News from the flavour frontier - heavy quark physics at the LHC

- Introduction
- Production (in brief)
- Decays
- Conclusions

Guy Wilkinson
University of Oxford

Flavour Physics is Important

Many of open questions in Standard Model (SM) found in flavour sector:

- Why are there 3 generations ? (and is it only 3 ?)
- What determines the extreme hierarchy of fermion masses?
- What determines the elements of the CKM matrix?
- What is the origin of CP violation (CPV)?

Progress in flavour physics may help understand open questions in cosmology - SM CPV insufficient to explain matter/antimatter asymmetry

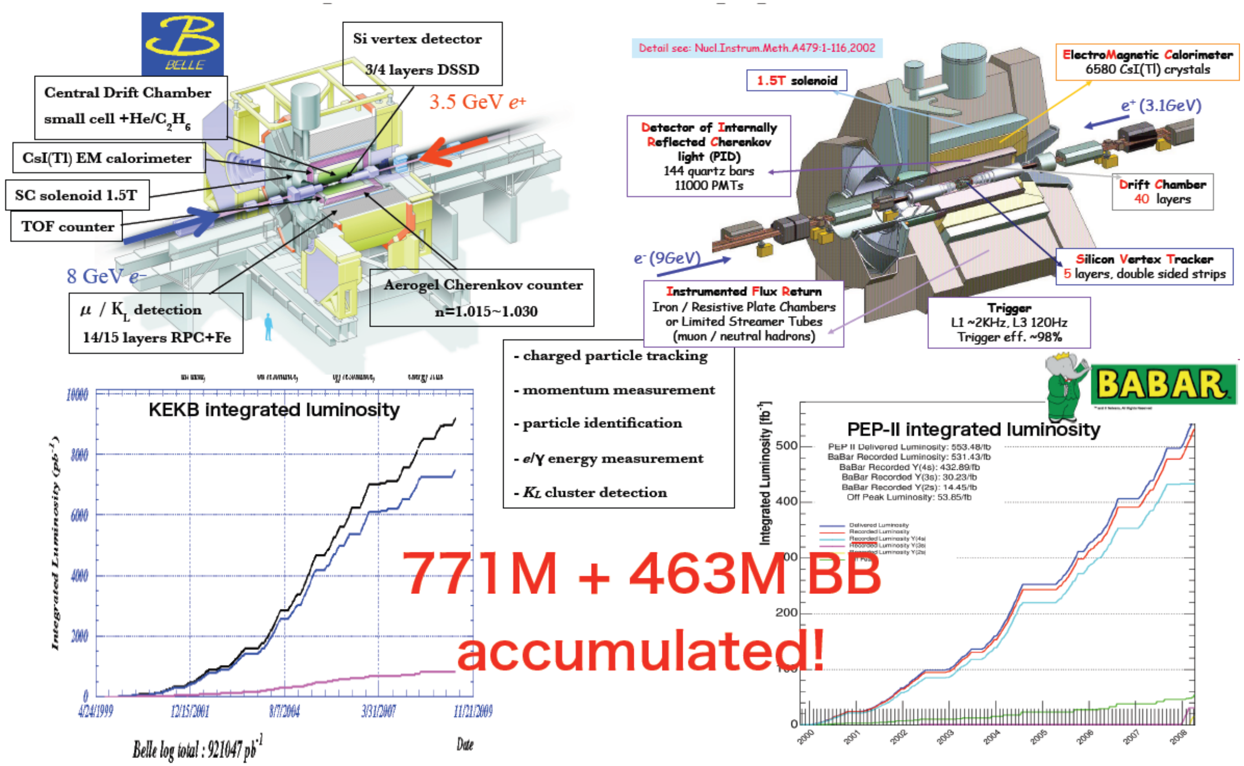
Flavour physics is a proven tool of discovery:

- Kaon mixing, BR($K^0_L \rightarrow \mu\mu$) & GIM → prediction of charm
- CP violation → need for a third generation
- B mixing → mass of top is very heavy
- SUSY parameter space already severely constrained by e.g. $b \rightarrow s\gamma$

Precise studies of flavour observables are an excellent way to look for New Physics!

Reign of the Υ(4S) machines

For most of the last decade flavour physics = BABAR + Belle, and e^+e^- was king



BABAR and Belle performed many beautiful and sophisticated analyses, making use of their pristine environment. But BABAR and Belle are no more. Instead…

Barbarians at the gate

Many flavour physicists have been wary about the onset of the LHC.

A 'dark ages' in which will be forgotten the sophistications of the previous era ?

I scorn your effete ways!

I lay waste to your inclusive, low background reconstructions!

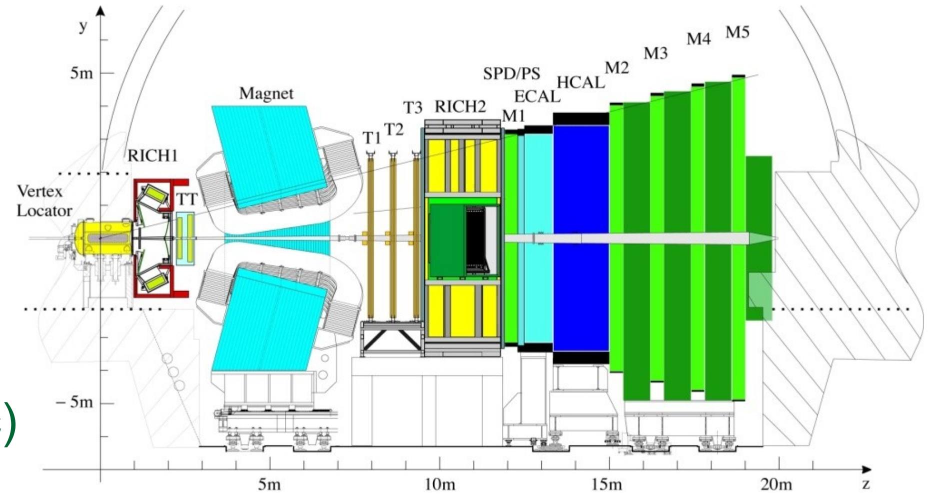
I bring desolation to all that is not high-p_T with leptons in the final state!

But there is no need to worry:

- Tevatron has already demonstrated flavour physics possible in hadronic environment
- Large cross-sections, high statistics...
- ...but also clean measurements possible...
- and also B_s, B_c and baryon studies!

LHCb Essentials

LHCb optimised for flavour physics.
Various attributes distinguish it from
Tevatron detectors + ATLAS/CMS:



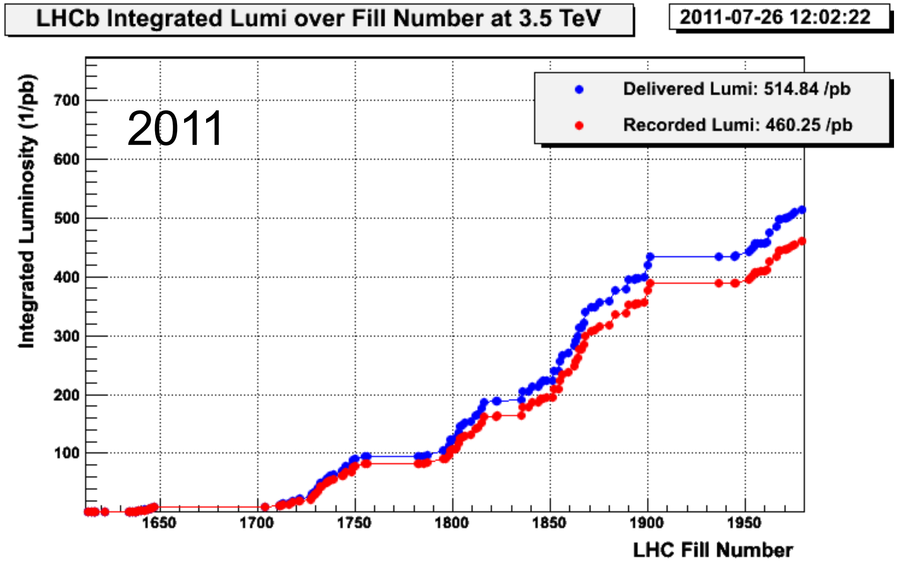
- Dedicated heavy flavour trigger
  - L0: hardware trigger firing on high p_t hadrons and muons (~few GeV/c)
  - HLT: software trigger exploiting, in particular, tracking and vertexing. Outputs at 3 kHz

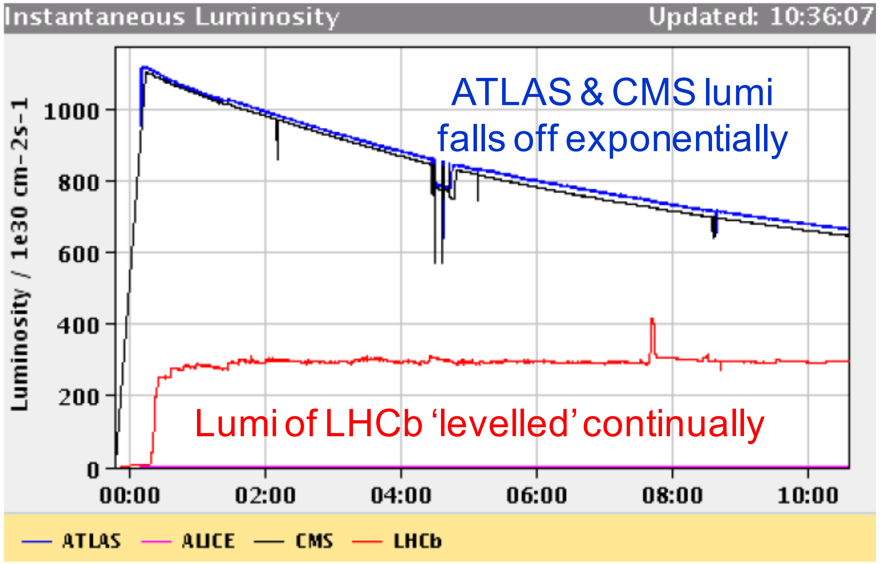
    → Efficient for hadronic B and D decays, as well as leptonic channels
- Very precise vertexing
  - VELO (planes of forward silicon) approach to within 8mm of beam
- Hadron identification
  - Two RICHes provide good π/K separation over $2 < p < 100$ GeV/c
- LHCb design luminosity << maximum design luminosity of machine
  - LHCb already operating at (even above!) design luminosity (2×10^{32} cm^{-2} s^{-1})

LHCb data taking

LHCb collected 37 pb^{-1} in 2010, and so far 460 pb^{-1} in 2011

2011 analyses presented today use up to ~330 pb^{-1}





Luminosity levelling delivers ~constant operation at 3 - 3.5 x 10^{32} cm^{-2} s^{-1}

Heavy Flavour Production

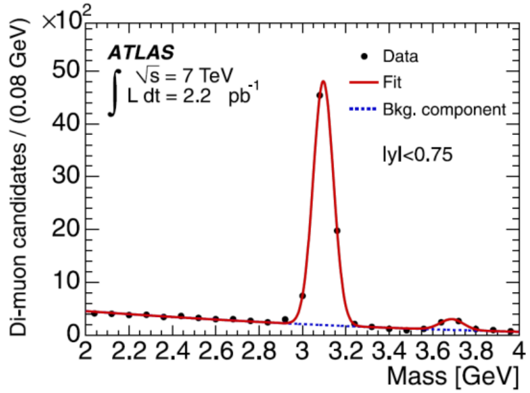
- Onia
- Exotics
- Open heavy flavour

Onia production

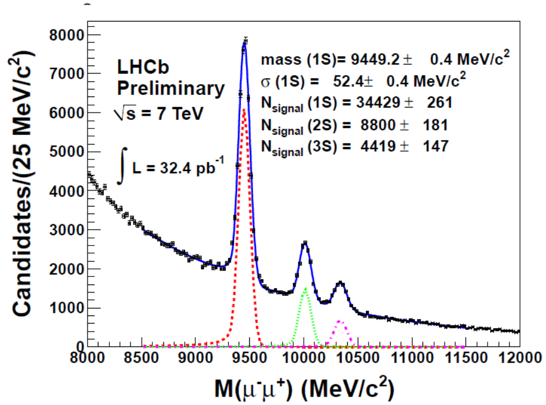
* also see ALICE, arXiv:1105.0380

Big challenge to understand mechanism of onia production: colour single model, octet model, evaporation model...? Measurements from all 4 LHC experiments*:

ATLAS, Nucl. Phys. B 850 (2011) 387

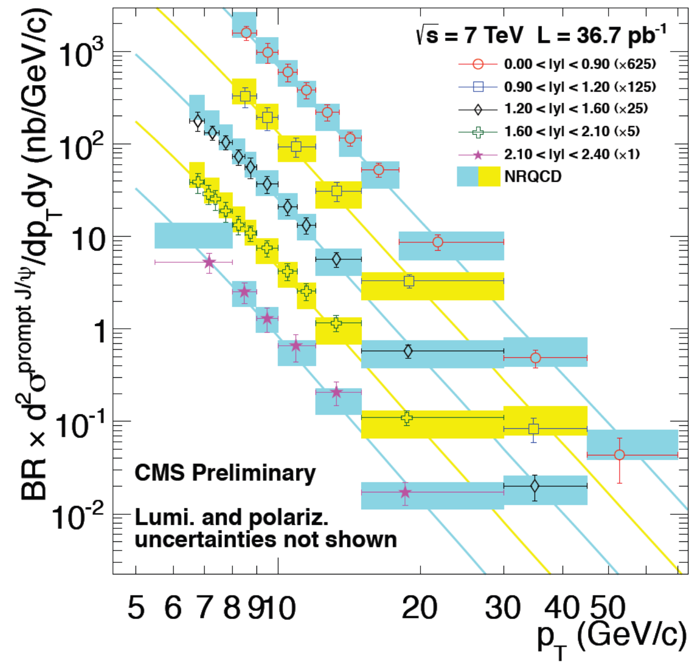


LHCb-CONF-2011-016



New J/Ψ [& Ψ(2S)] results from CMS with full 2010 dataset

CMS PAS BPH-10-014



good agreement with NRQCD ! [also for Ψ(2S)]

More precise than theory (modulo polarisation assumption)! Need new observables:

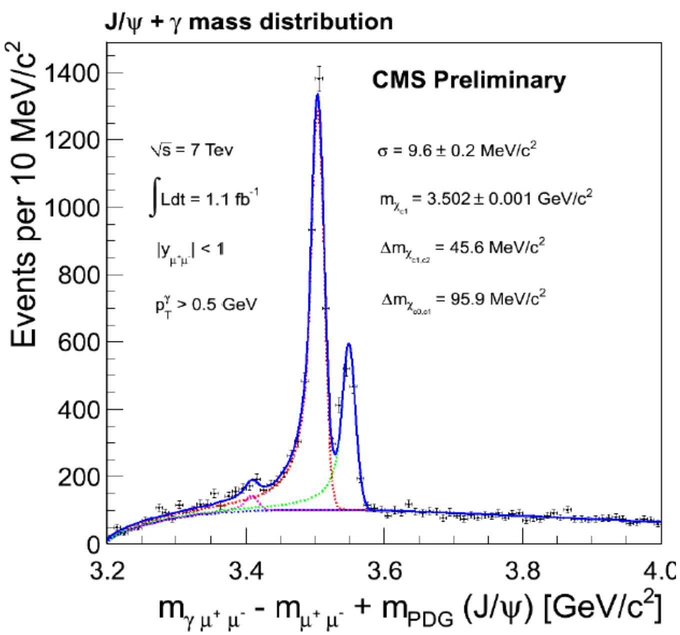
- more studies of higher states, e.g. Ψ(2S), χ_c – some available already
- polarisation measurements – a powerful discriminant. Coming soon!

Radiative decays of χ_c states

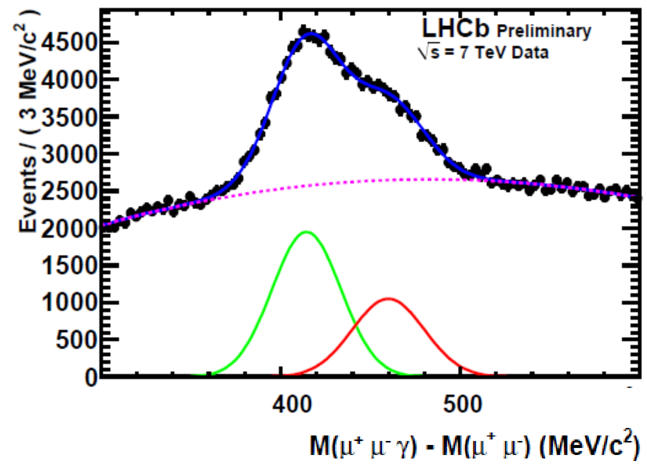
First studies of radiative decays $\chi_c \rightarrow J/\Psi\gamma$! Challenge is to resolve χ_{c1} vs χ_{c2}

Using tracks from γ conversions

CMS DPS – 2011/011

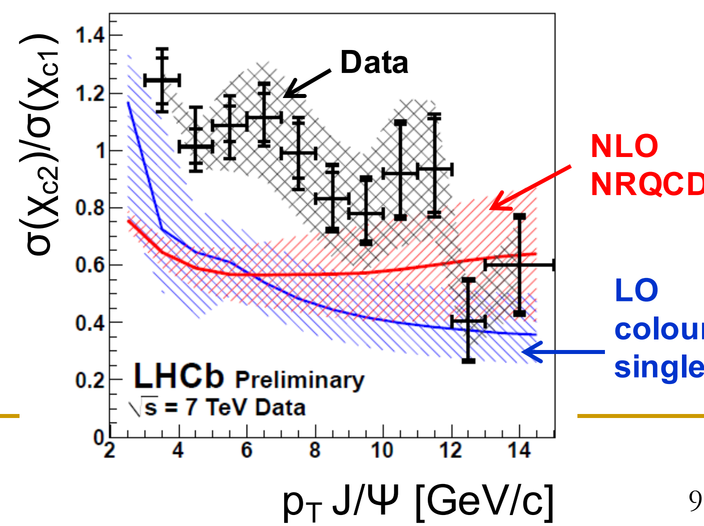


ECAL based approach



LHCb-CONF-2011-020

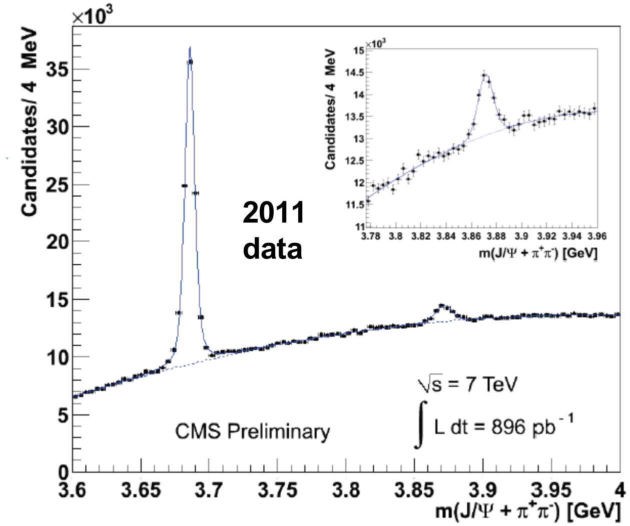
First results for relative production of χ_{c2} vs χ_{c1} are not in good agreement with NLO NRQCD predictions



Learning about exotics: X(3872)

LHC experiments are starting to study the X(3872) - observation, xsection & mass:

CMS-DP-2011-009
2010 production analysis:
CMS PAS BPH-10-018



Ratio of inclusive X(3872) to Ψ(2S) production times branching ratio for $J/\Psi\pi^+\pi^-$ decay mode

$$R = 0.087 \pm 0.017(stat.) \pm 0.009(syst.)$$

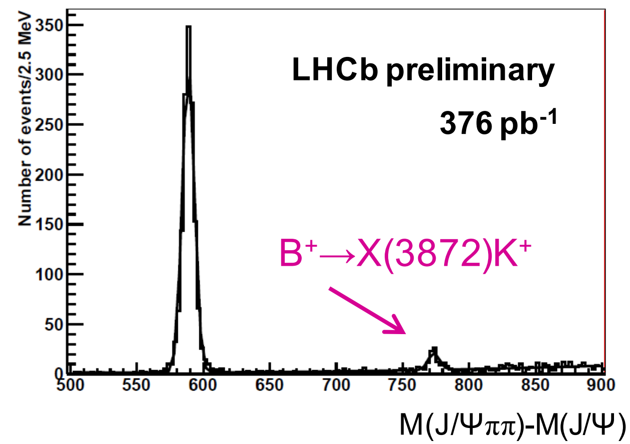
for $p_T(X) > 8$ GeV/c and $|y(X)| < 2.2$ (2010 data).

LHCb inclusive 2010 measurements:

$$M_{X(3872)} = 3871.96 \pm 0.46(\mathrm{stat}) \pm 0.10(\mathrm{syst})\ \mathrm{MeV}/c^2$$

$$\sigma_{X(3872)} \times \mathcal{BR}(X(3872) \to J/\psi\pi^+\pi^-) = 4.74 \pm 1.10(\mathrm{stat}) \pm 1.01(\mathrm{syst})\ \mathrm{nb}$$

LHCb-CONF-2011-021
LHCb-CONF-2011-043



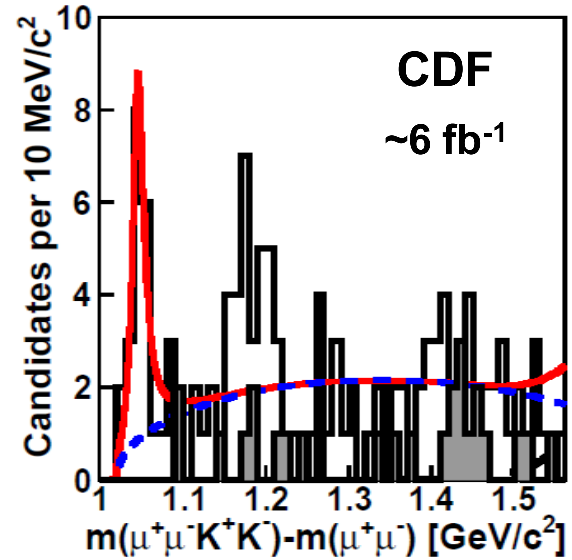
With 2011 data it will be possible to perform very precise mass measurements as well as angular studies* in B→X(3872)K to learn about the J^{PC} of the X(3872)

* see LHCb-PUB-2010-003

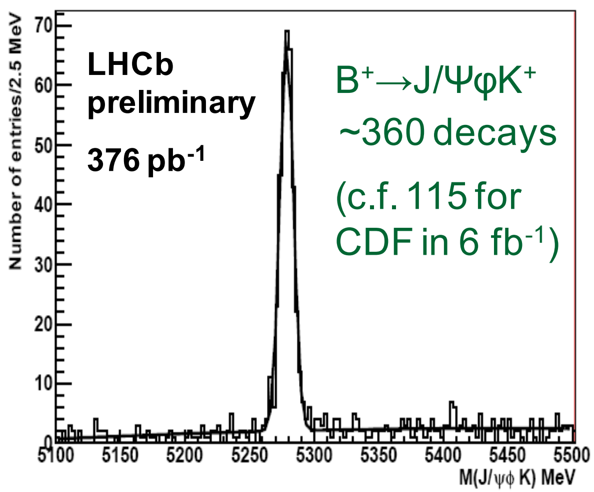
Search for the X(4140)

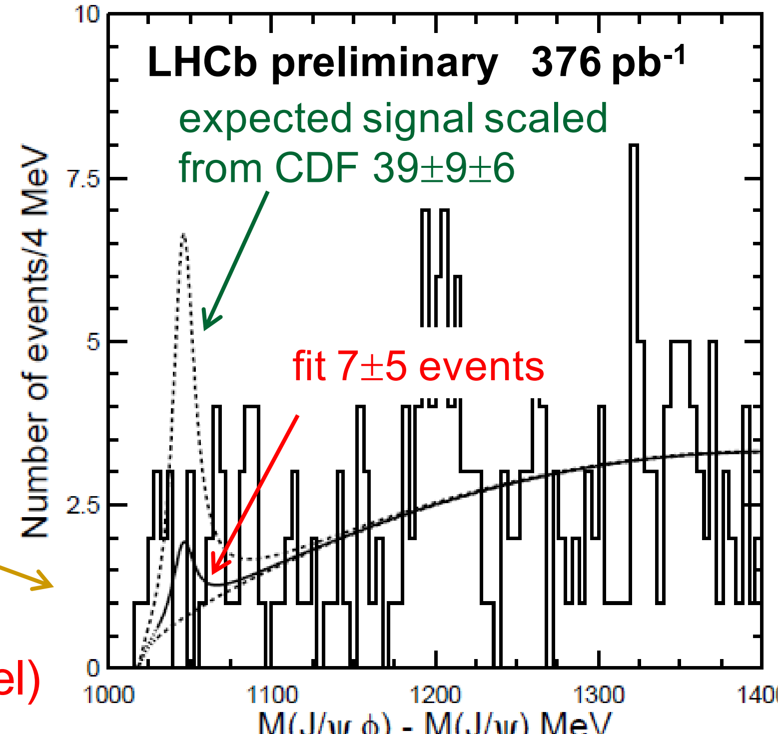
Studies of other possible exotics are underway.

CDF reported observation of narrow structure, X(4140), in the $m(J/\Psi K^+K^-)-m(J/\Psi)$ spectrum in $B^+\rightarrow J/\Psi\phi K^+$ 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

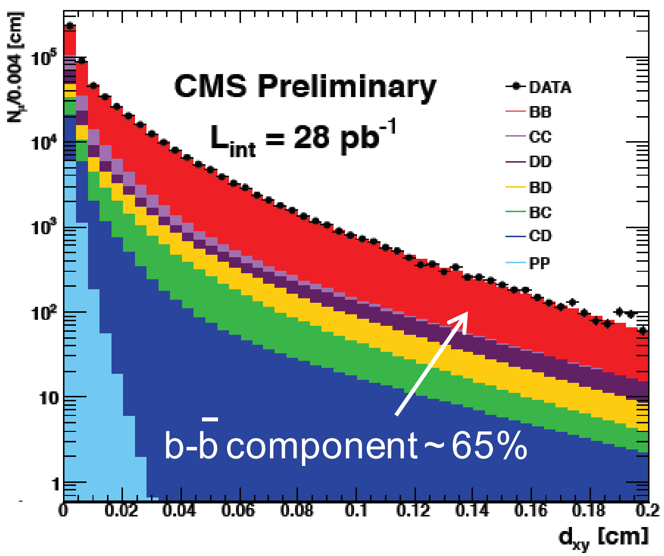
LHCb does not confirm presence of X(4140). 2.4σ tension with CDF (using this bckgd model)

b-hadron production

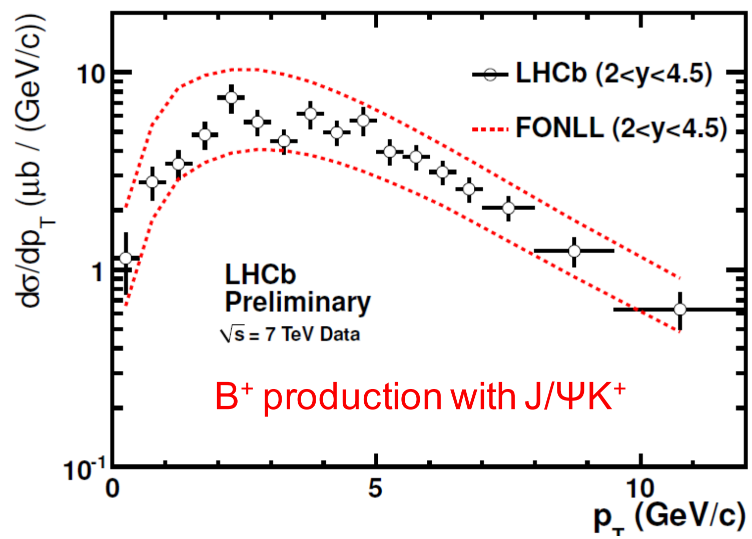
B production studied with displaced J/Ψ tag (ATLAS, CMS, LHCb), D+μ tag (LHCb), fully reconstructed J/ΨX states (LHCb, CMS) and lepton and dilepton tags (CMS)

New CMS dimuon study
μ's with $p_T > 4$ GeV, $|\eta|<2.1$.
Fit to IP distributions.

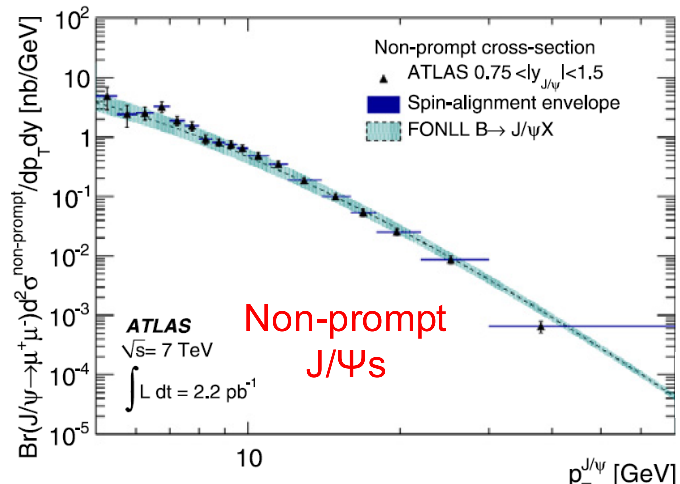
CMS PAS BPH-10-015



$$\sigma(pp \to b\bar{b}X \to \mu\mu Y) = 26.18 \pm 0.14\,(\text{stat.})$$
$$\pm 2.82\,(\text{syst.}) \pm 1.05\,(\text{lumi.})\ \text{nb}$$



LHCb-CONF-2011-033



ATLAS, Nucl. Phys. B 850 (2011) 387

All measurements reasonably well described by theory (FONLL, MC@NLO) – an achievement!

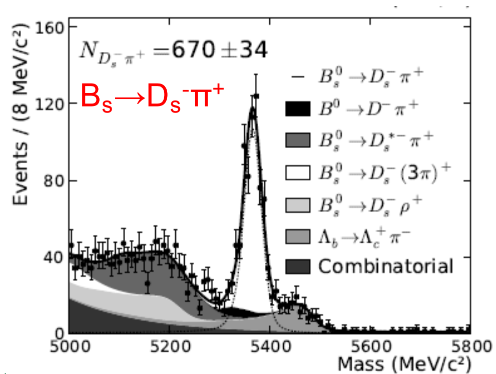
b-production: going deeper

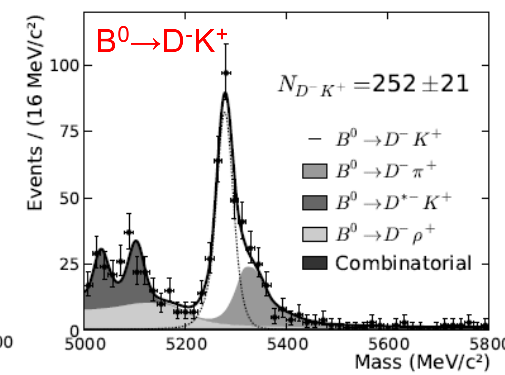
Other observables under study (e.g. $B\bar{B}$ correlations [CMS, JHEP 1103 (2011) 136])

LHCb has measured the fragmentation fractions: the relative rates of B^+,B^0,B_s,Λ_b...

Two complementary approaches:

1. ratio of related hadronic decays, e.g. $B^0 \rightarrow D^- K^+$ and $B_s \rightarrow D_s^- \pi^+$ [arXiv:1106.4436, sub. to PRL]





2. semi-leptonic analysis with $D^0 \mu X$, $D^+ \mu X$, $D_s \mu X$ & $\Lambda_c \mu X$ events and accounting for cross-feeds [LHCb-CONF-2011-028]

Consistent results for B_s/B^0 fragmentation ratio, f_s/f_d, which thus can be combined:

$$\boxed{\langle f_s / f_d \rangle_{LHCb} = 0.267 \,^{+0.021}_{-0.020}} \; *$$

f_s/f_d not a priori a ‘universal’ number, but agreement nonetheless seen with other measurements:

$$\langle f_s / f_d \rangle_{\substack{LEP \\ Tevatron}} = 0.271 \pm 0.027 \; ^{x}$$

Necessary input for e.g. BR($B_s \rightarrow \mu\mu$) !

* LHCb-CONF-2011-034
x courtesy Olivier Schneider

Charm and beauty hadron decays

- Charm physics – Cinderella goes to the ball
- Precise CKM metrology – the gateway to γ
- A_{FB} in $B^0 \rightarrow K^{*0}\mu^+\mu^-$
- Two-body charmless B decays
- New observations in b-baryon decays (for examples of new B_s and B_c decays see backups)
- Hot topics in the B_s sector
  - CPV in B_s-B_s oscillations
  - B_s->μ+μ-

B-factory domain

Beyond the Y(4S)

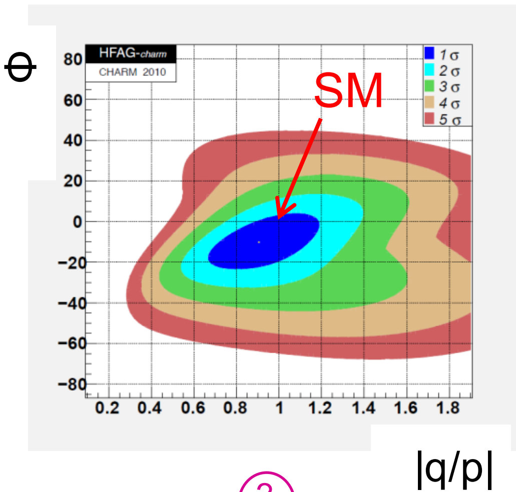
Cinderella goes to the ball: the search for CPV in charm

Charm physics was regarded as poor relation of flavour studies – this has been changed by discovery of mixing

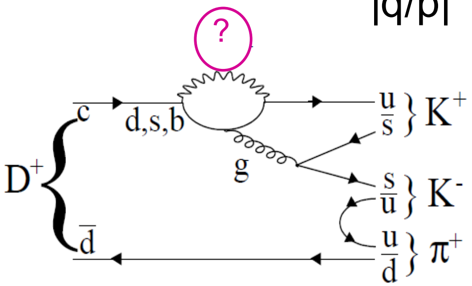
- Mixing parameters x,y are small (~1%) but still larger than anticipated. Any CP violating effects in mixing (SM or NP) are driven by these parameters.

  Real incentive to look for CPV in D mixing, which in SM is negligible, but can be enhanced in many models

Existing constraints on CPV in mixing are weak!



- Direct CPV best looked for in Singly Cabibbo suppressed decays, where gluonic Penguins are significant.
  Here it is possible even SM could generate a signal !



The 6.5 mb cross-section means that charm is abundant at LHC, but can measurements be performed with these low p_T decays in this environment ?

Measurement of A_Γ at LHCb

new today!

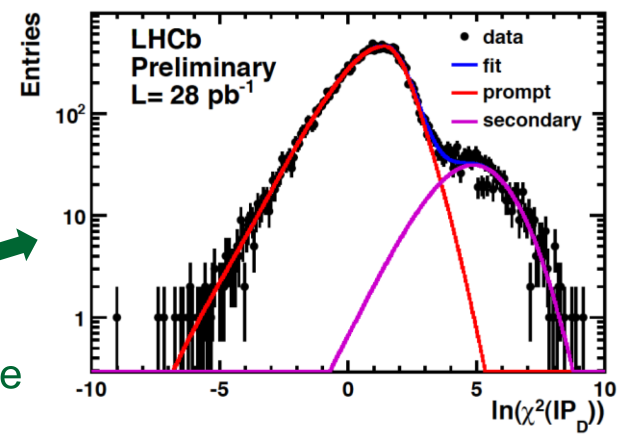
Search for non-zero value of A_Γ is one of most important ways to search of CP-violation in charm mixing

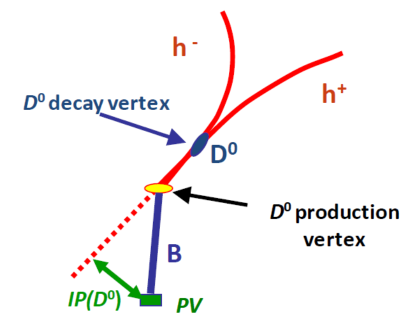
$$A_\Gamma = \frac{\tau\left(\overline{D}^0 \to K^-K^+\right) - \tau\left(D^0 \to K^-K^+\right)}{\tau\left(\overline{D}^0 \to K^-K^+\right) + \tau\left(D^0 \to K^-K^+\right)}$$

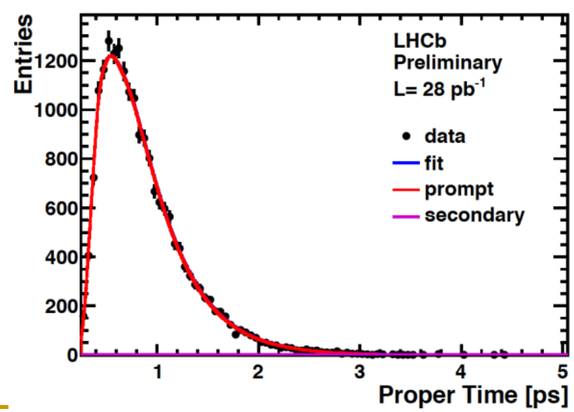
Preliminary A_Γ measurement now available from LHCb using 28 pb^{-1} of 2010 data, using $D^* \to D^0\pi$, $D^0 \to K^+K^-$ decays

Two main challenges in time-dependent charm studies at LHC:

- Understand 'pollution' to prompt charm sample coming from $B \to DX$
- Understand lifetime trigger acceptance







Obtained event-by-event in data !

Preliminary result:

A_Γ= (- 0.59 ± 0.59 ± 0.21) x 10^{-2}

c.f. world average: 0.12 ± 0.25

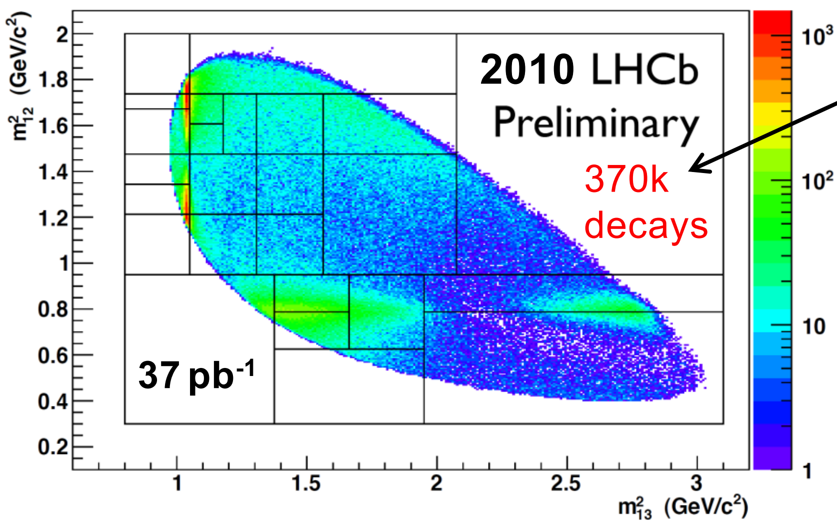
Recall this with only fraction of 2010 data...

LHCb-CONF-2011-046

Direct CPV search at LHCb

Perform model independent binned CPV search in singly Cabibbo suppressed $D^+ \to K^- K^+ \pi^-$ events

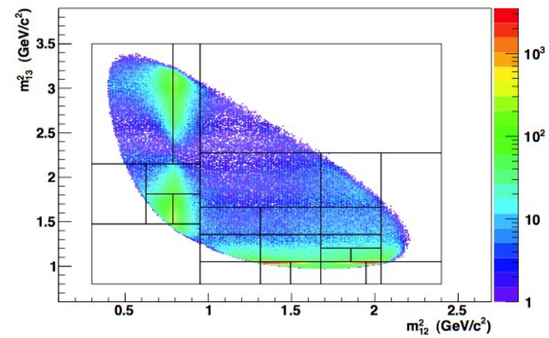
Paper in preparation



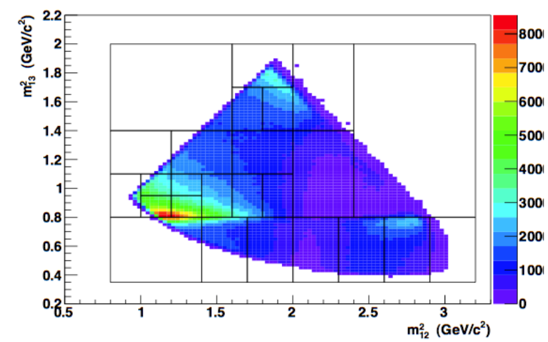
Compare with 43k events in BABAR 80 fb^{-1} study [PRD 71 (2005) 091101 (R)]

Cabibbo favoured control modes (no CPV expected)

Same topology $D_s^+ \to K^+ K^- \pi^+$



10x more abundant $D^+ \to K^- \pi^- \pi^+$

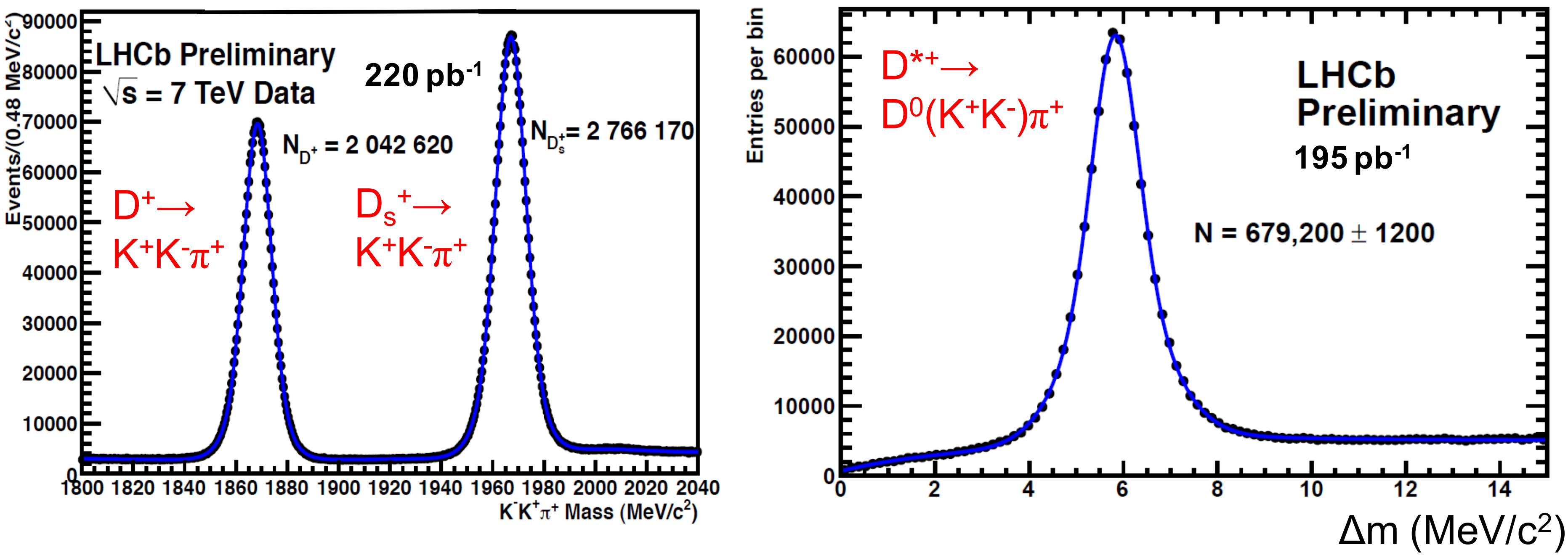


- Normalise D^+ vs D^- to remove production asymmetries
- Use a resonance motivated binning & a uniform binning
- Look for statistically significant difference in D^+ vs D^- bin contents (method based on PRD 80 (2009) 096006)
- Look for fake CPV in sidebands and control modes

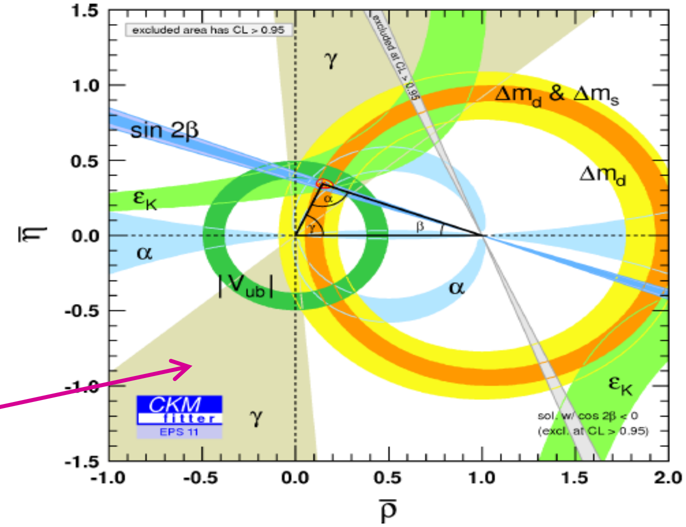
No fake CPV seen – data & method very robust against biases !

No evidence of CPV for signal in any binning

Good prospects for 2011 charm studies



Precision CKM-metrology: the next challenge



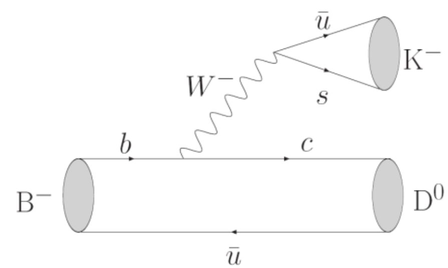
B-factories (& others) have done a great job in mapping out unitarity triangle. But progress needs improved knowledge of angle γ (a.k.a. φ_3)

Look in $B^\pm \to DK^\pm$ decays using common mode for D^0 & $\bar{D}^0$

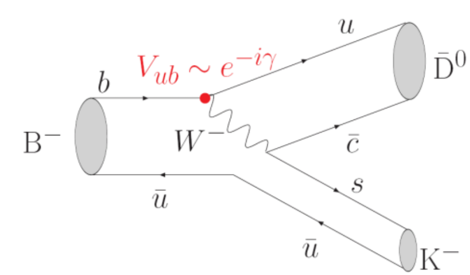
→γ sensitive interference

→ different rates for B^+ & B^- (CPV!)

Favoured



Suppressed



To *maximise* interference look for mode *suppressed* for D^0 & *favoured* for $\bar{D}^0$

e.g. $D^0 \to K^+\pi^-$ (DCS) , $\bar{D}^0 \to K^+\pi^-$ (CF)

the 'ADS' method [Atwood, Dunietz, Soni]

Total visible BR very small (~10^{-7}), and not yet observed (4.1σ signal from Belle).

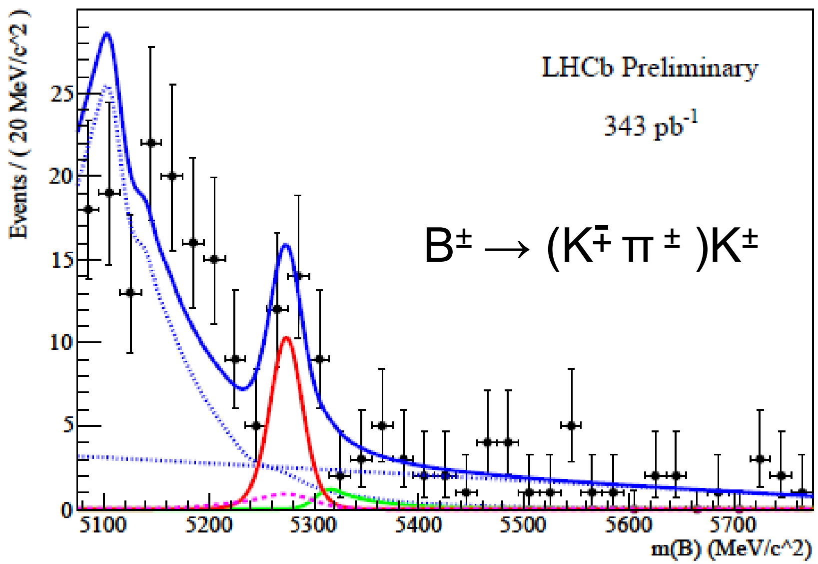
The suppressed 'ADS' mode $B^\pm \to (K^\mp\pi^\pm)K^\pm$ is the gateway to γ !

Evidence for suppressed ADS mode

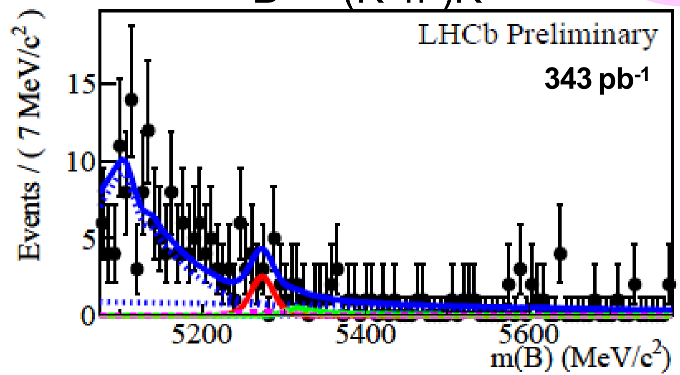
new today!

LHCb-CONF-2011-044

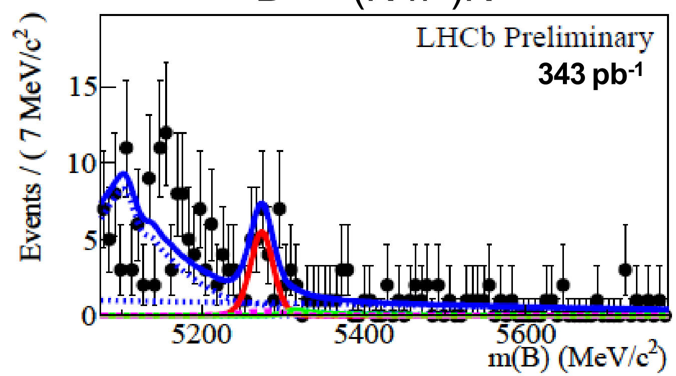
Signal seen with 4.0σ significance, & hint of asymmetry, consistent with previous results



$B^- \rightarrow (K^+\pi^-)K^-$



$B^+ \rightarrow (K^-\pi^+)K^+$



Ratio to favoured mode:

$$R_{ADS}^{DK} = (1.66 \pm 0.39 \pm 0.24) \times 10^{-2}$$

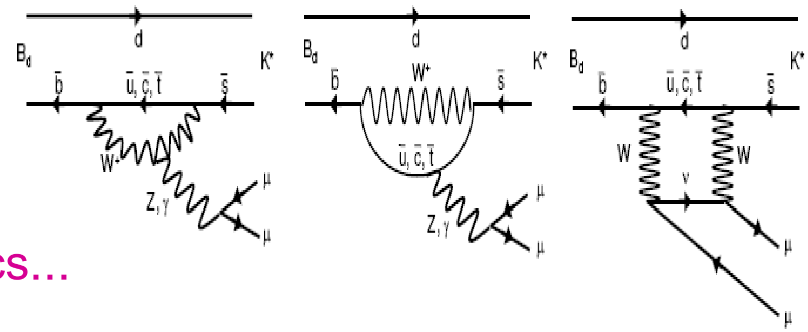
World Average (without LHCb) 1.6 ± 0.3

Asymmetry:

$$A_{ADS}^{DK} = -0.39 \pm 0.17 \pm 0.02$$

World Average (without LHCb) -0.58 ± 0.21

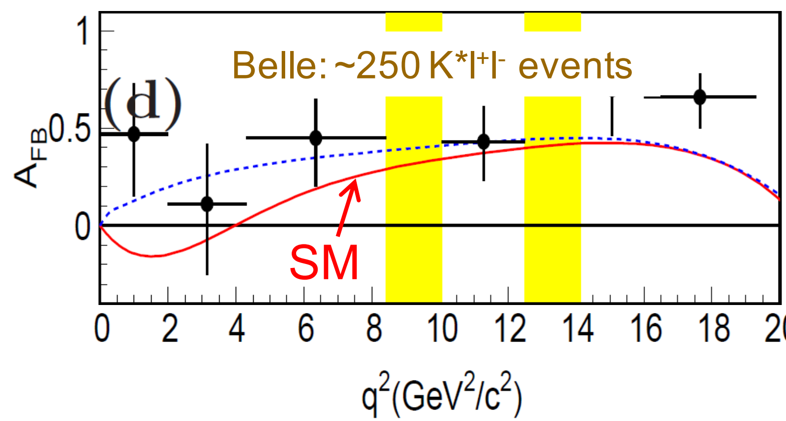
$B^0 \rightarrow K^* l^+ l^-$



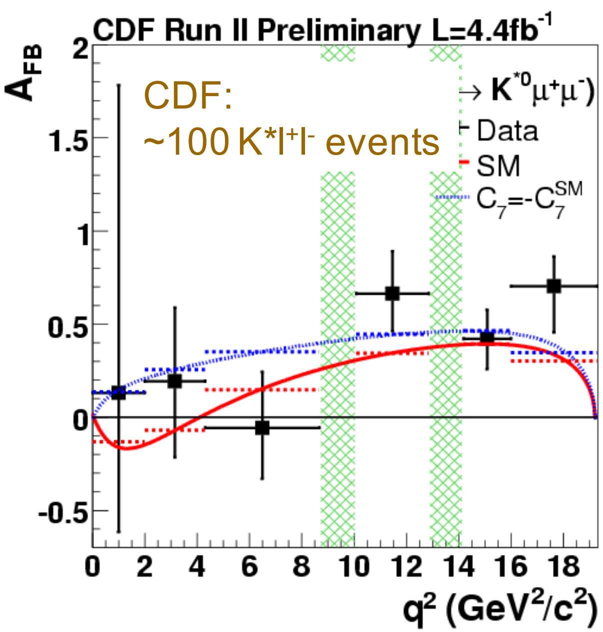
Many observables exist in $B^0 \rightarrow K^* l^+ l^-$ to probe helicity structure of any New Physics...

...in particular, forward-backward asymmetry (A_{FB}) of lepton system as a function of lepton invariant mass (q^2).

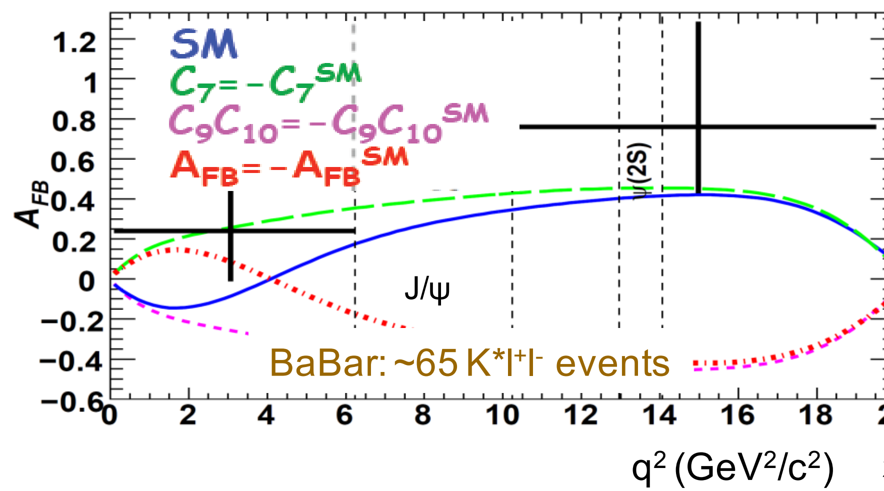
Early results from CDF & B-factories show intriguing behaviour at low q^2, But precision too low yet to speak of an 'anomaly'



PRL 103 (2009) 171801



CDF note 10047

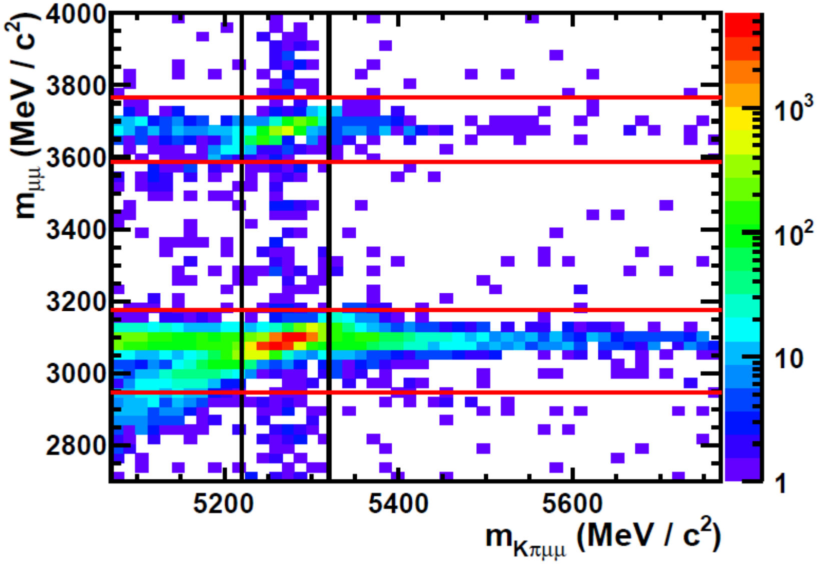


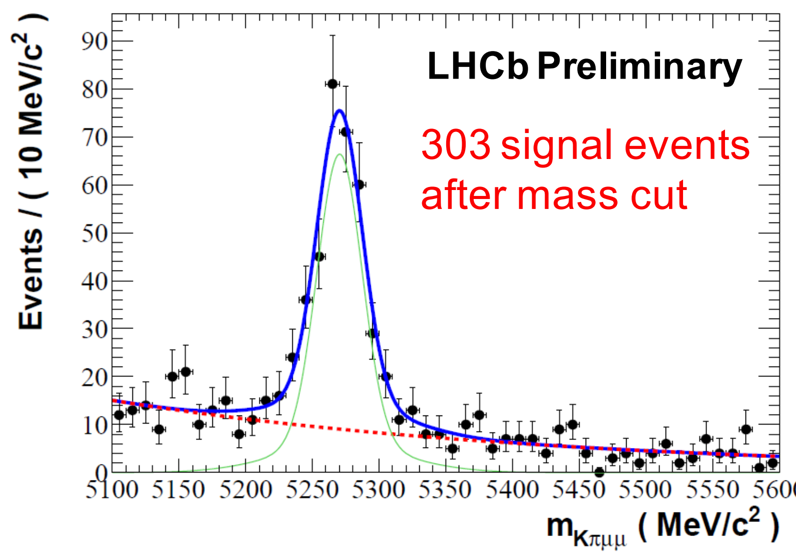
PRD 79 (2009) 031102

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

Select events using Boosted Decision Tree from sample of 309 pb^{-1}

Veto decays in J/Ψ and $\Psi(2S)$ resonance regions





Measure in 6 q^2 bins:

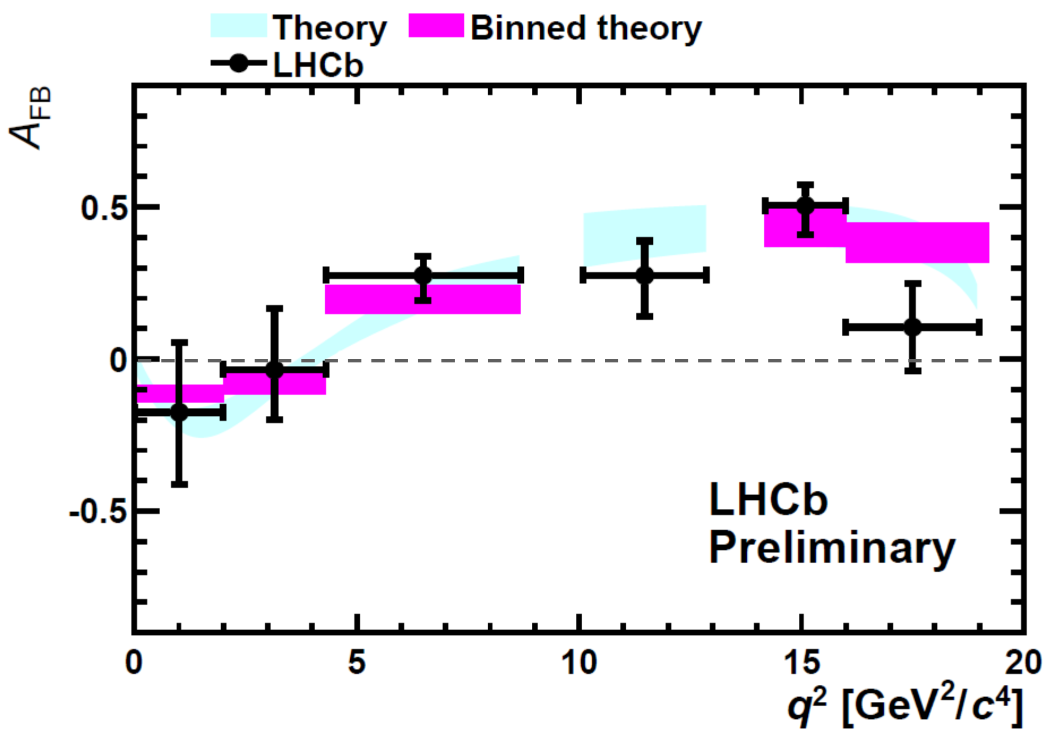
- differential branching fraction, $d\Gamma/dq^2$
- longitudinal polarisation, F_L
- A_{FB}

Simultaneous fit of 1D projections of helicity angles of kaon & lepton

Performance of fit validated on MC and $B^0 \to J/\Psi K^*$ decays

A_{FB} in $B^0 \to K^* \mu^+ \mu^-$ in LHCb with 309 pb^{-1}

Systematic uncertainties are small, and generally themselves statistics limited.



LHCb-CONF-2011-038

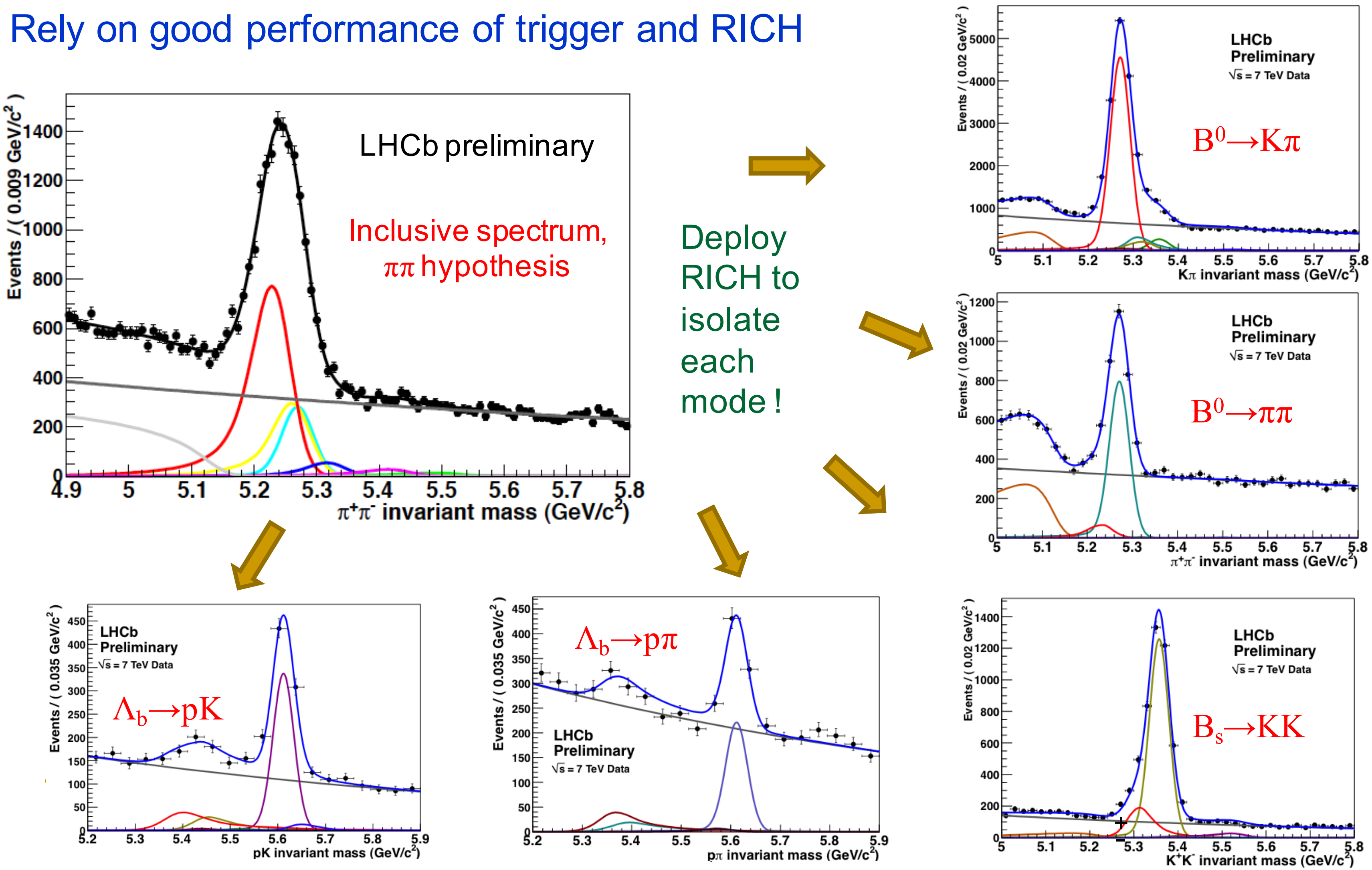
Data are consistent with predictions at present sensitivity. Next tasks:

- determine crossing point: sensitive to NP; cleanly predicted in SM
- study other observables, e.g. $A_T^{(2)}$, sensitive to RH currents

The RICHness of ‘B→hh’ (h=π,K,p)

Two-body charmless B decays are central goal of LHCb physics. Significant contribution of Penguin diagrams provides entry point for New Physics

Rely on good performance of trigger and RICH

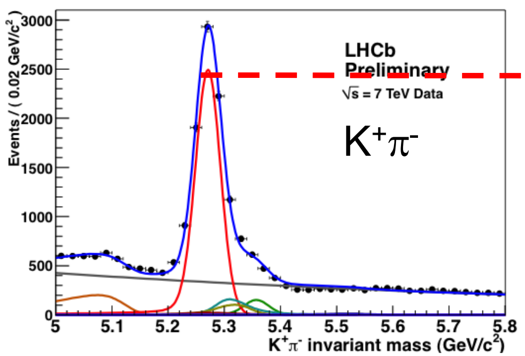


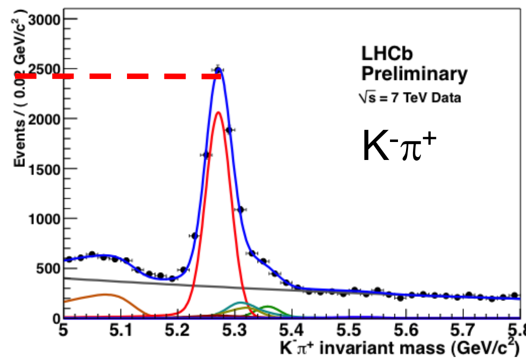
A closer look at $B_{d,s}\rightarrow K\pi$: direct CPV

The ultimate goal is to perform time dependent study, particularly of $B_s\rightarrow KK$: this will enable New Physics sensitive measurement of γ [e.g. Fleischer, PLB 459 (1999) 306]

First step: look for direct CPV in flavour specific final states [LHCb-CONF-2011-042]:

- Focus on $B^0\rightarrow K\pi$ - here, significant CPV well established





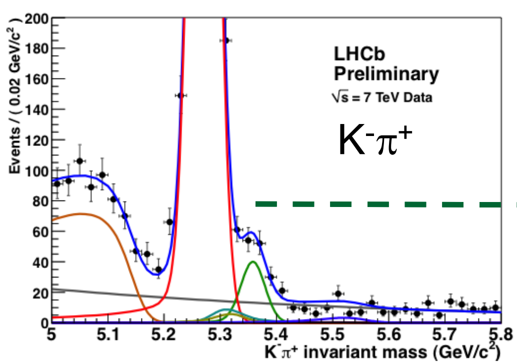
$$A_{CP}(B^0 \rightarrow K^+\pi^-) = -0.088 \pm 0.011(\text{stat}) \pm 0.008(\text{syst})$$

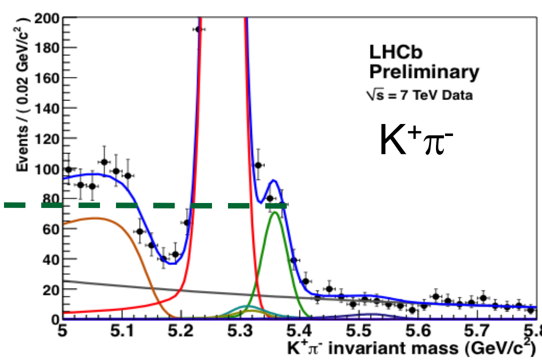
Existing world average:

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

Most precise single measurement and first 5σ observation of CPV at a hadron machine !

- Now look at $B_s\rightarrow K\pi$





$$A_{CP}(B_s^0 \rightarrow \pi^+K^-) = 0.27 \pm 0.08(\text{stat}) \pm 0.02(\text{syst})$$

CDF result:

$$A_{CP}(B_s^0 \rightarrow \pi^+K^-) = 0.39 \pm 0.17$$

First evidence of CPV in B_s decays !

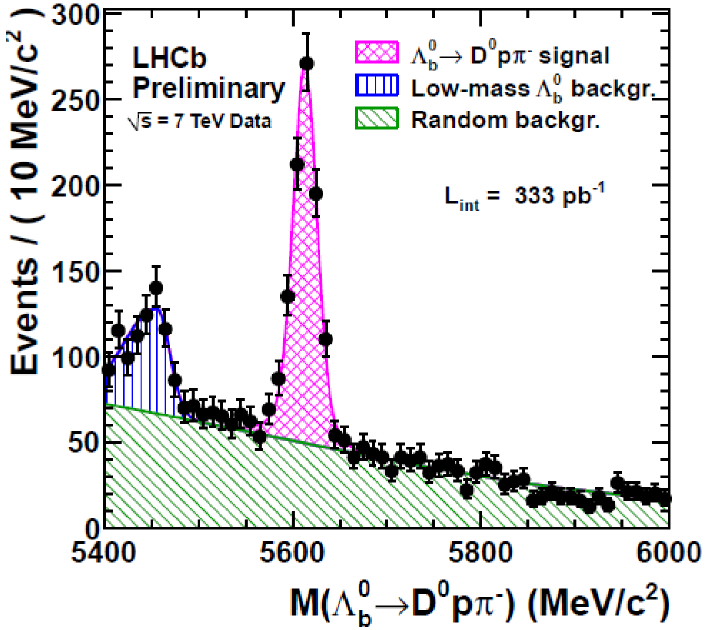
New measurements with b-baryons

new today!

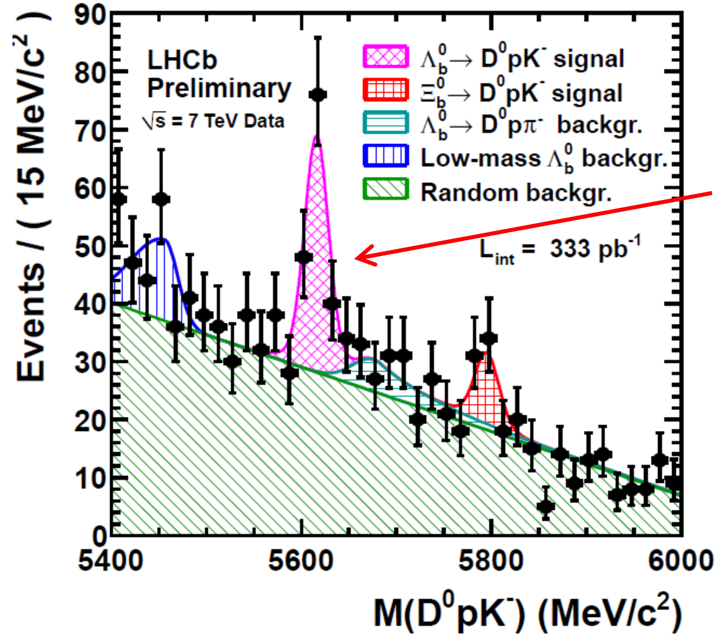
Interesting to look for the decay $\Lambda_b \to D^0 pK$, as it is a potentially powerful mode for measuring CKM angle γ. First step is to reconstruct normalisation mode $\Lambda_b \to D^0 p\pi$

LHCb-CONF-2011-036

$D^0 p\pi^-$



$D^0 pK^-$



$\Lambda_b \to D^0 pK$

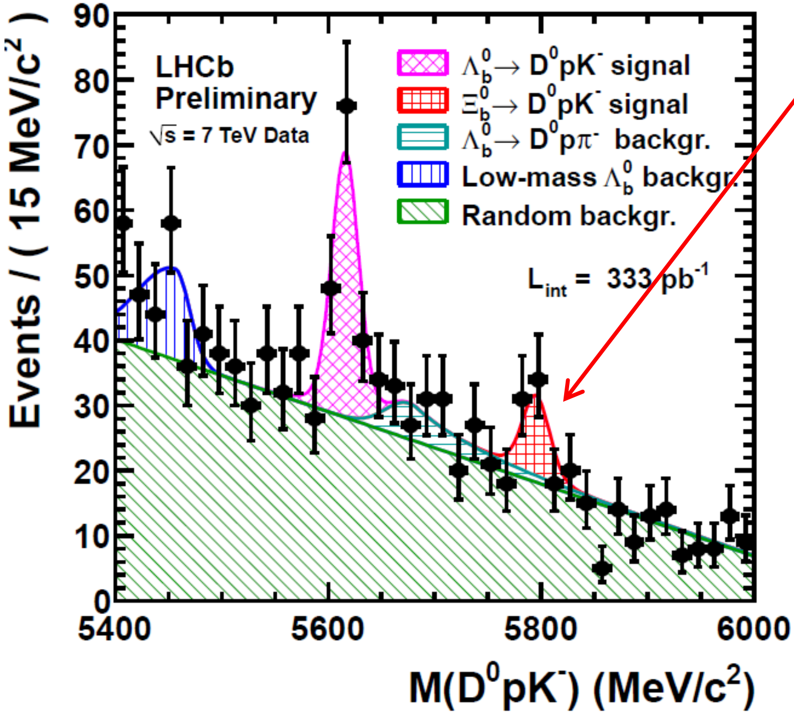
$\Lambda_b \to D^0 pK$ observed for first time with significance of 6.3σ

$$\frac{\mathcal{B}(\Lambda_b^0 \to D^0 pK^-)}{\mathcal{B}(\Lambda_b^0 \to D^0 p\pi^-)} = 0.112 \pm 0.019^{+0.011}_{-0.014}$$

New measurements with b-baryons

new today!

Looking closer at the D^0pK^- there is a signal ~5.8 GeV/c^2 with statistical + systematic significance of 2.6 σ. Consistent with $\Xi^0_b \to D^0pK^-$ decay.



$\Xi^0_b \to D^0pK$

Measure relative production rate x BR:

$$\frac{f_{b\to\Xi^0_b} \times \mathcal{B}(\Xi^0_b \to D^0pK^-)}{f_{b\to\Lambda^0_b} \times \mathcal{B}(\Lambda^0_b \to D^0pK^-)} = 0.29 \pm 0.12 \pm 0.08$$

Measure mass relative to Λ_b:

$$m(\Xi^0_b) - m(\Lambda^0_b) = (181.8 \pm 5.5 \pm 0.5)\ \mathrm{MeV}/c^2$$

Ξ^0_b [$\to \Xi_c^+\pi^-$, $\Xi_c^+ \to \Xi^-\pi^+\pi^-$, $\Xi^- \to \Lambda\,\pi^-$, $\Lambda \to p\pi^-$] recently observed by CDF [arXiv:1107.4015].

Consistent masses from two experiments: $m_{LHCb} - m_{CDF}$ (Ξ^0_b) = -14.6 $\pm$ 8.5 MeV/c^2

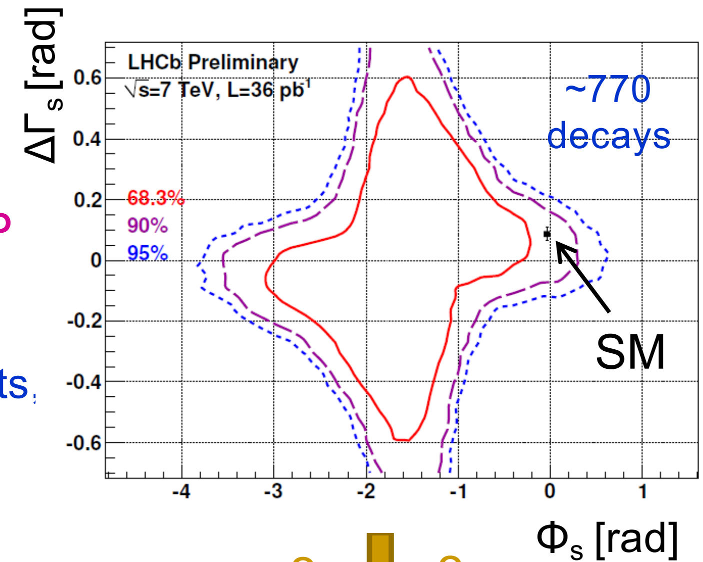
CPV in B_s mixing

CPV phase in B_s mixing-decay interference, φ_s, measured in $B_s \to J/\Psi\varphi$ a golden observable for NP

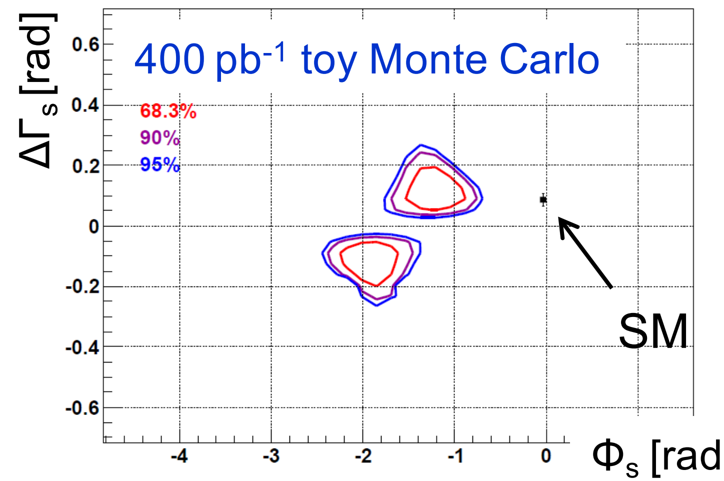
- a priori: unprobed box diagram, phase small in SM
- a posteriori: tension with SM in Tevatron measurements, and synergy with D0 dilepton asymmetry study

LHCb 37 pb^{-1} result: less precise than Tevatron, but shows the same trend. ~350 pb^{-1} currently under analysis – exciting possibilities await !

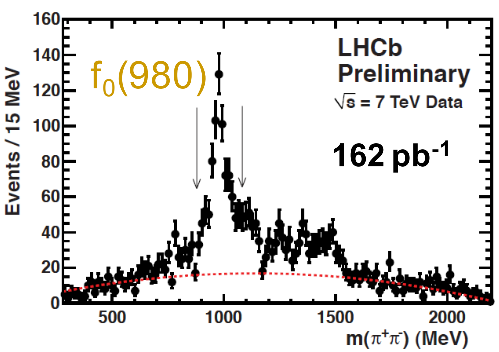
Sensitivity can be improved through inclusion of CP-eigenstate modes such as $B_s \to J/\Psi f_0(980)$



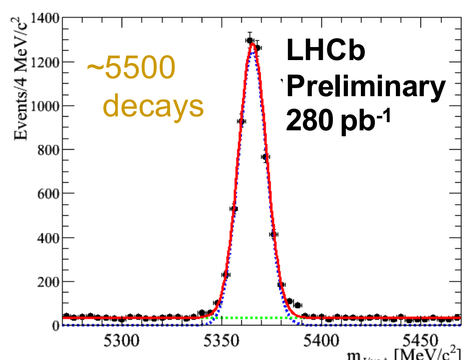
? ?



Assuming identical analysis performance + central values



$\pi\pi$ spectrum in $B_s \to J/\Psi\pi\pi$

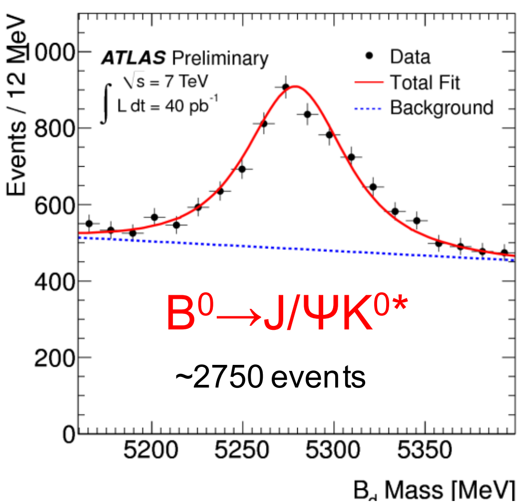


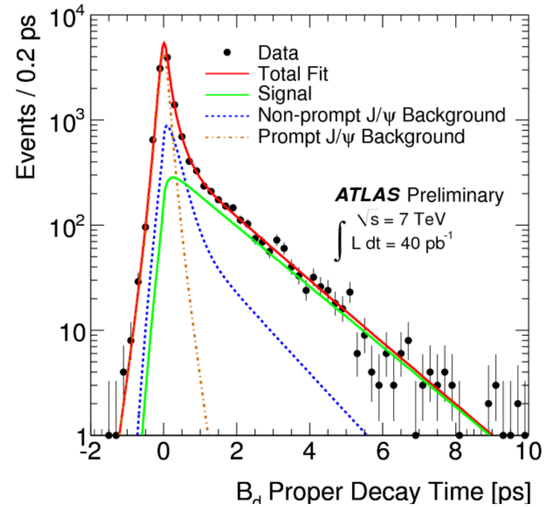
$B_s \to J/\Psi\varphi$

ATLAS lifetime results

Preliminary measurements of B-lifetimes indicate that ATLAS is well prepared to play important role in LHC φ_s campaign & other b-decay studies with di-muons

ATLAS-CONF-2011-092

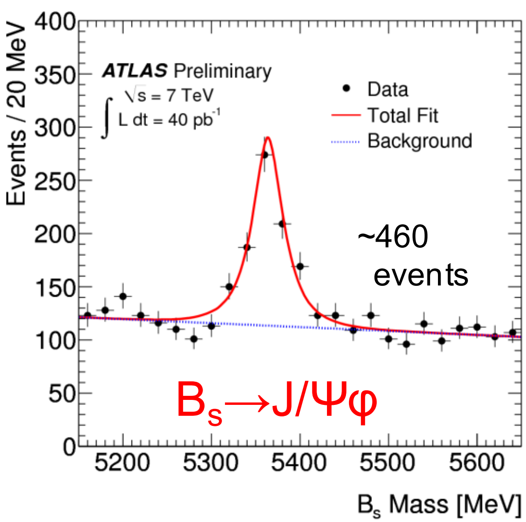


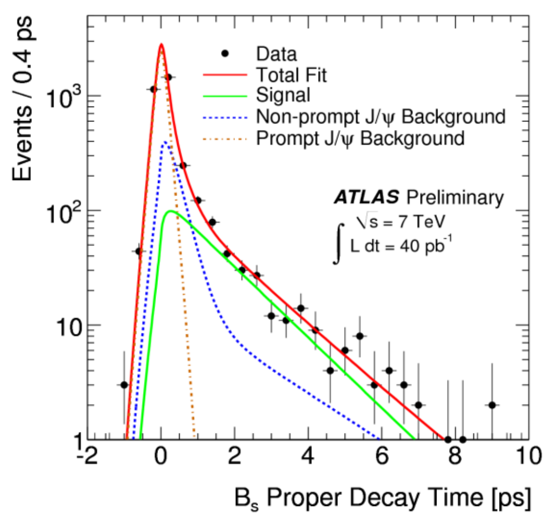


Simultaneous mass & lifetime fit:

$$\tau_{B_d} = 1.51 \pm 0.04\ (\text{stat}) \pm 0.04\ (\text{syst})\ \text{ps}$$

(PDG: 1.525 ± 0.009 ps)





$$\tau_{B_s single} = 1.41 \pm 0.08\ (\text{stat}) \pm 0.05\ (\text{syst})\ \text{ps}$$

(fit with single exponential)

(PDG: 1.472 ± 0.026 ps)

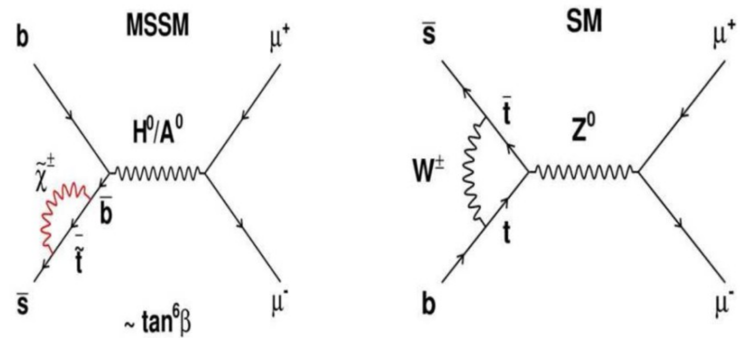
The golden mode: $B_s \to \mu\mu$

B physics rare decay par excellence:

$$BR(B_s \to \mu\mu)_{SM} = (3.2 \pm 0.2) \times 10^{-9}$$

[A.J.Buras, arXiv:1012.1447]

Precise prediction (which will improve) !

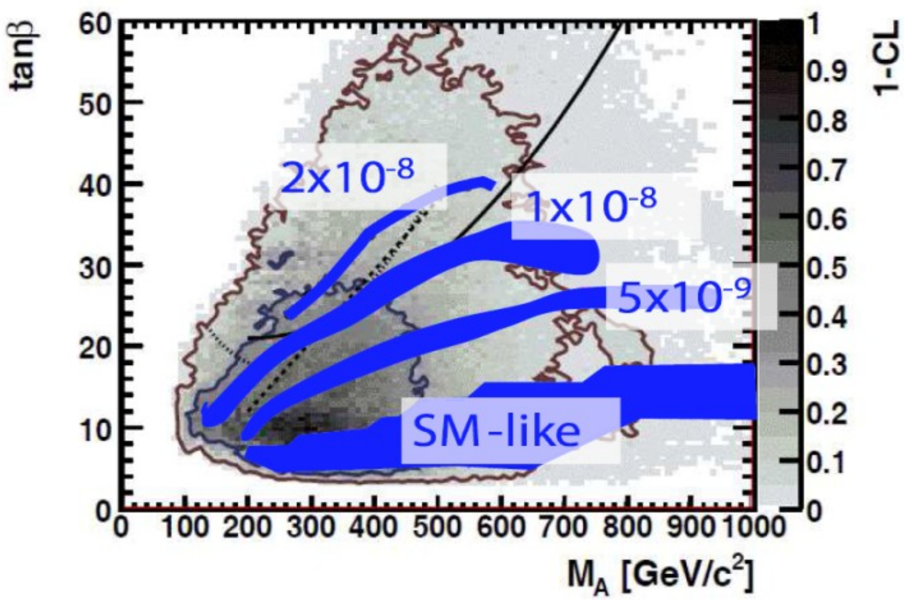


Very high sensitivity to NP, eg. MSSM:

$$Br^{MSSM}(Bq \to l^+ l^-) \propto \frac{m_b^2 m_l^2 \tan^6 \beta}{M_{A0}^4}$$

One example [O. Buchmuller et al, arXiv:0907.5568] : NUHM (= generalised version of CMSSM)

$BR(B_s \to \mu\mu)$ - highly discriminatory



BR UL 95% CL as of Spring 2011:

CDF (3.7 fb^{-1}): $< 4.3 \times 10^{-8}$

D0 (6.1 fb^{-1}): $< 5.1 \times 10^{-8}$

LHCb (37 pb^{-1}): $< 5.6 \times 10^{-8}$

Recent exciting hint from CDF (7 fb^{-1}):

$$BR = 1.8^{+1.1}_{-0.9} \times 10^{-8} \quad !?!$$

[arXiv:1107.2304]

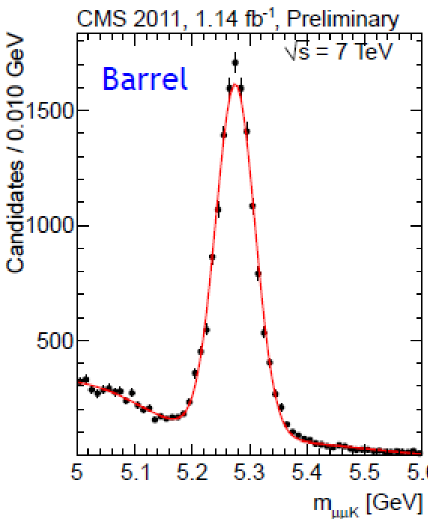
CMS search for $B_{s,d} \to \mu^+\mu^-$ with 1.14 fb^{-1}

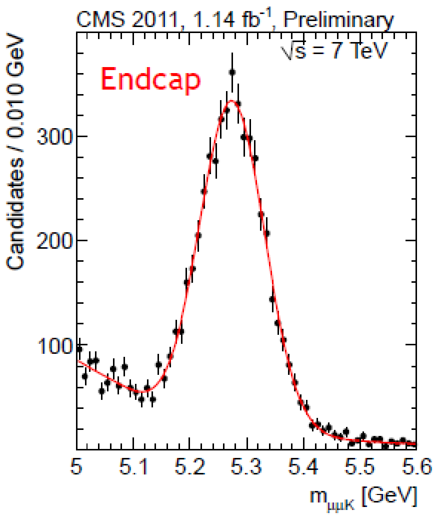
Dimuon trigger at L1, with track information added at HLT. Then, offline:

- Cut based analysis, optimised on MC and data sidebands prior to unblinding
- Analysis divided into two geometrical regions

	'Barrel'	'Endcap'
	Both μ $|\eta|<1.4$	At least one μ $|\eta|>1.4$

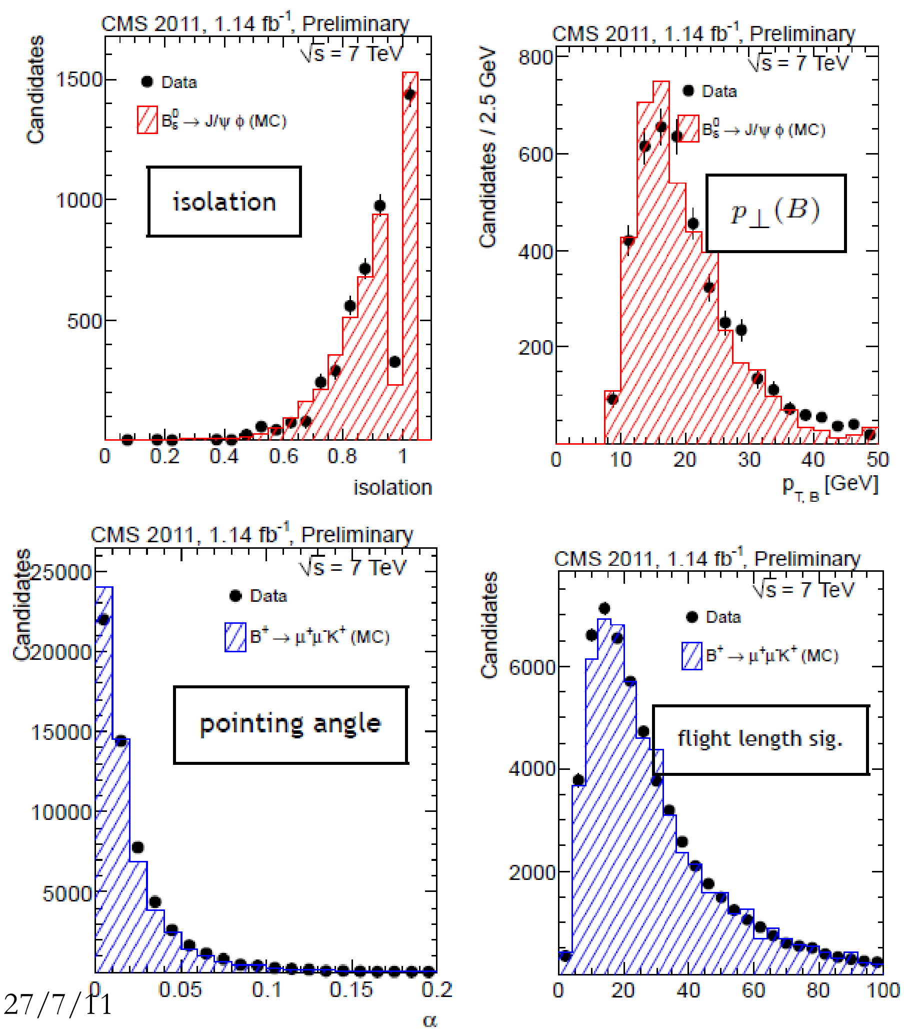
- Selection variables: μ id, 'pointing angle', flight length significance, fit quality, isolation criteria, $p_T(\mu\text{-max}) > 4.5$ GeV, $p_T(\mu\text{-min}) > 4.0$ GeV, $p_T(B) > 4$ GeV...
- Normalisation & calibration modes:
  - $B^+ \to J/\Psi K^+$
  - $B_s \to J/\Psi \varphi$ used to check MC description of B_s fragmentation dependent quantities



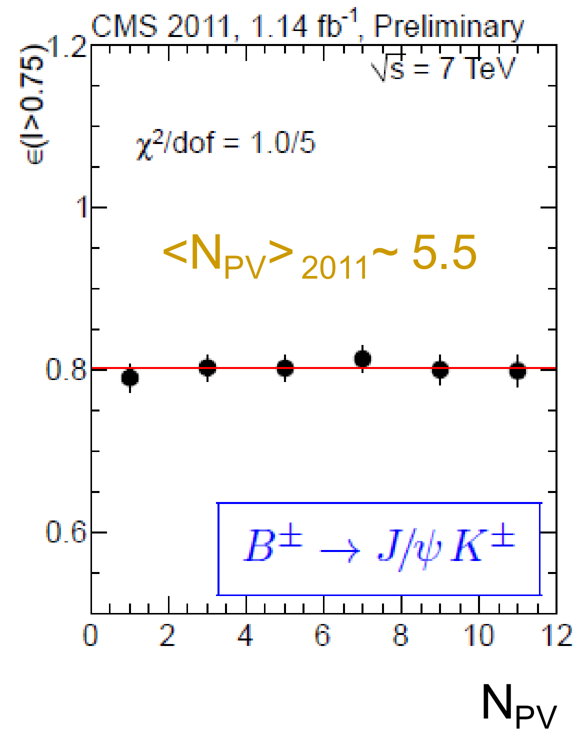


CMS $B_s \to \mu^+\mu^-$ analysis performance

Good agreement found between data and MC for all selection variables.



Efficiency of variables potentially sensitive to pileup (e.g. isolation, flight length) checked on data



Excellent stability observed – good news for higher luminosity!

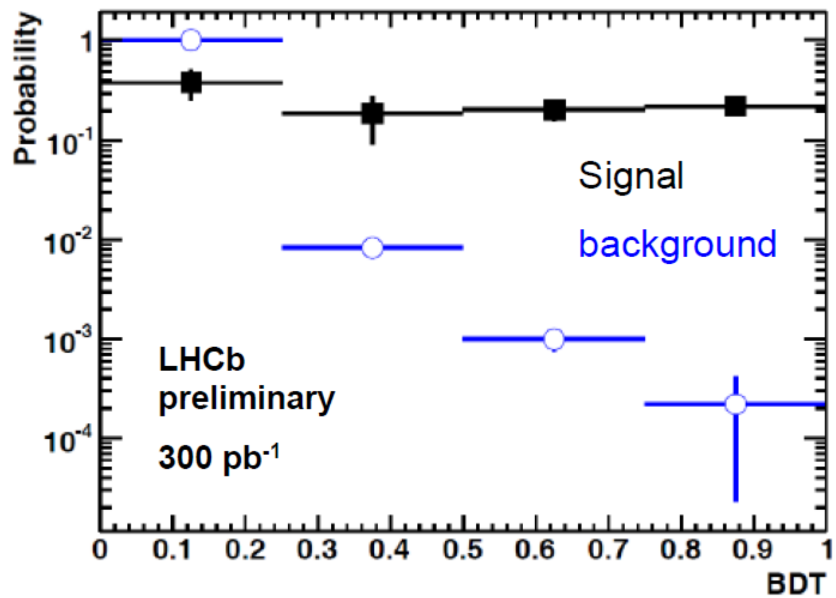
2011 $B_s \to \mu^+\mu^-$ search at LHCb with 300 pb^{-1}

Strategy very similar to 2010 analysis
[PLB 699 (2011) 330] After di-μ preselection:

- Build Boosted Decision Tree out of 9 kinematical and topological variables

  Train BDT on MC, but calibrate on data:

  - signal response: use B→hh decays triggered on 'other B' (avoid biases!)
  - background response: use sidebands



- Invariant mass of expected signal parameterised as crystal ball, with scale & resolution (~25 MeV) calibrated from data (dimuon resonances & B→hh)
- Now look in a 6 x 4 grid of $\mu^+\mu^-$ invariant mass vs BDT output
- To obtain relative BR for signal use three normalisation channels: $B^+ \to J/\Psi K^+$, $B_s \to J/\Psi\varphi$ and $B^0 \to K\pi$ – all give consistent results

Do we see a peak ?

Doigt de Dieu, or Pic Central de la Meije (3973m).
Not far from Grenoble...

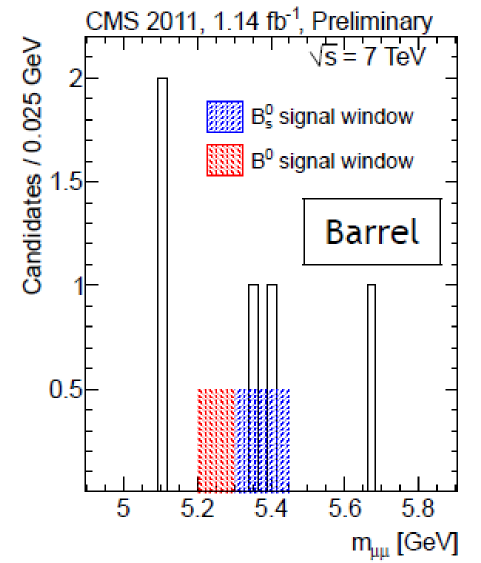
Not exactly…

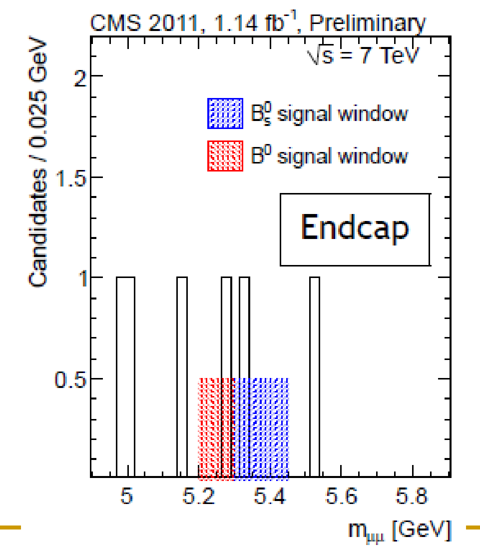
CMS results for $B_s \to \mu^+\mu^-$ search with 1.14 fb^{-1}

No significant excess seen

	Barrel	Endcap
N^{exp}_{signal}	0.80 ± 0.16	0.36 ± 0.07
N^{exp}_{bg}	0.60 ± 0.35	0.80 ± 0.40
N^{exp}_{peak}	0.07 ± 0.02	0.04 ± 0.01
N_{obs}	2	1

this is $B \to hh$





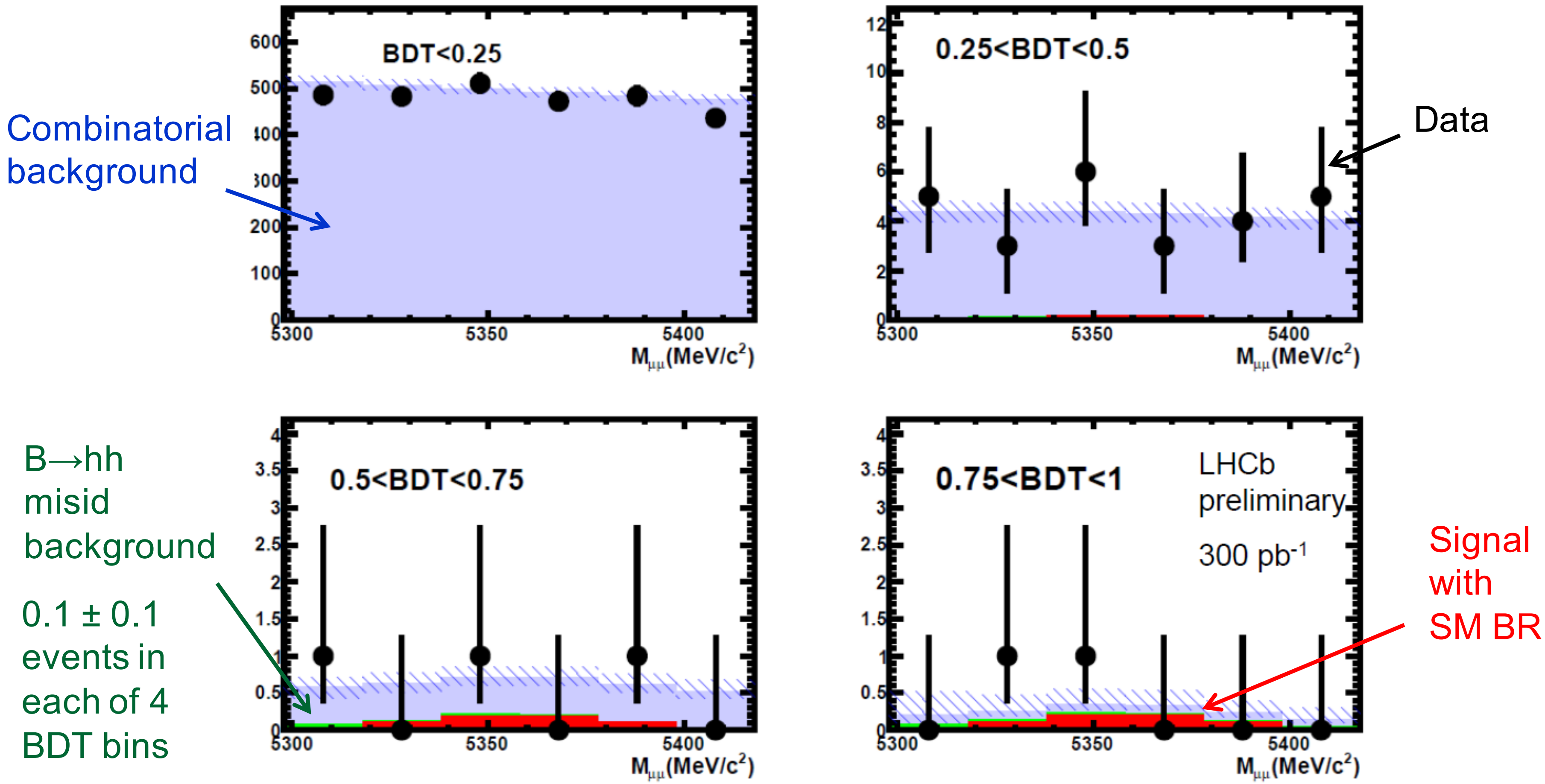
Calculate upper limits using frequentist CLs approach and taking $f_s/f_u = 0.282 \pm 0.037$ [PDG]

Expected limit at 95% C.L. (including presence of SM signal) — 1.8×10^{-8}

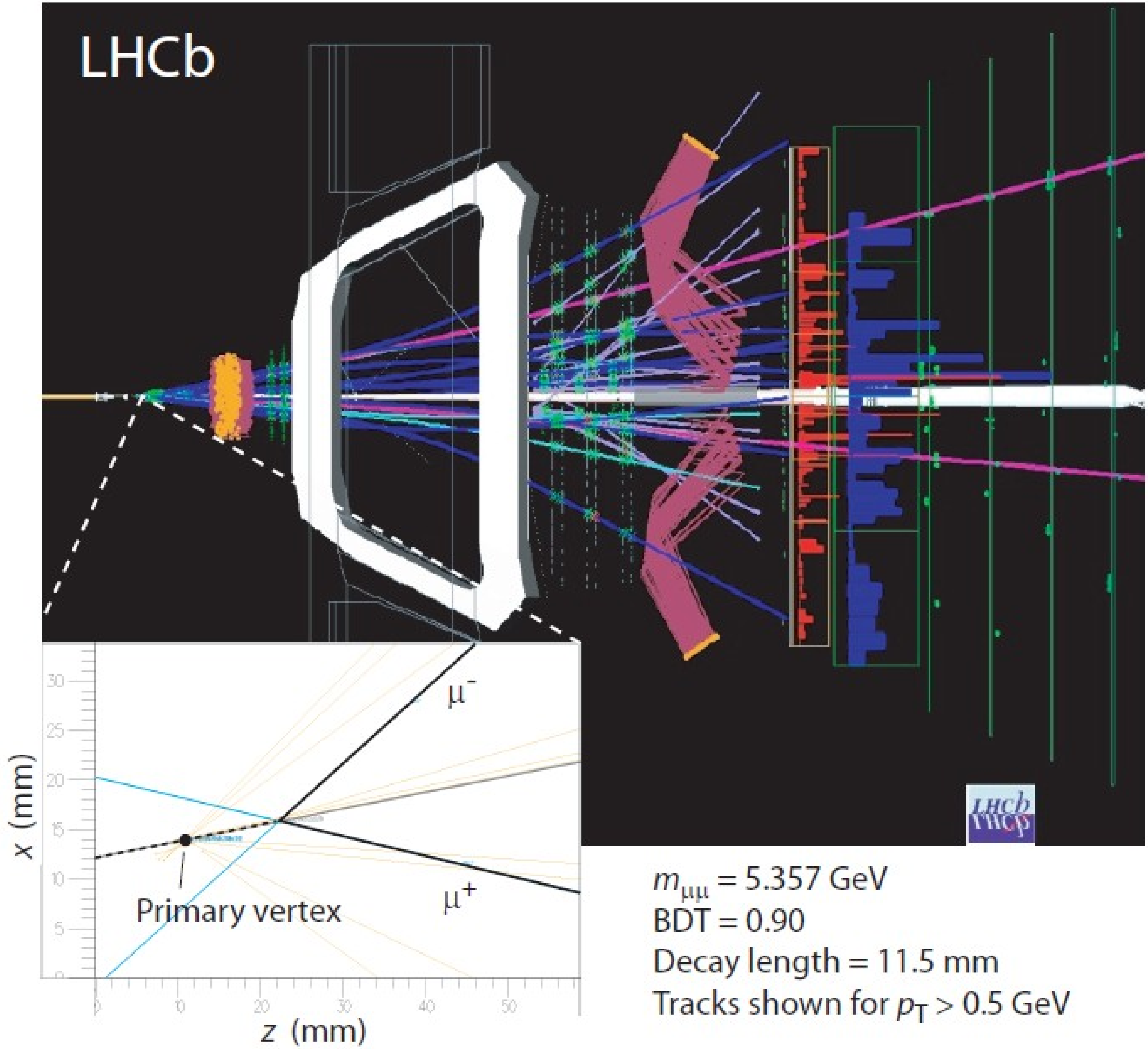
Observed limit at 95% (90%) C.L. — $\boxed{1.9\ (1.6) \times 10^{-8}}$

p-value of bckgd only hypothesis — 11%

LHCb $B_s \to \mu^+\mu^-$ results in B_s mass region with 300 pb^{-1}



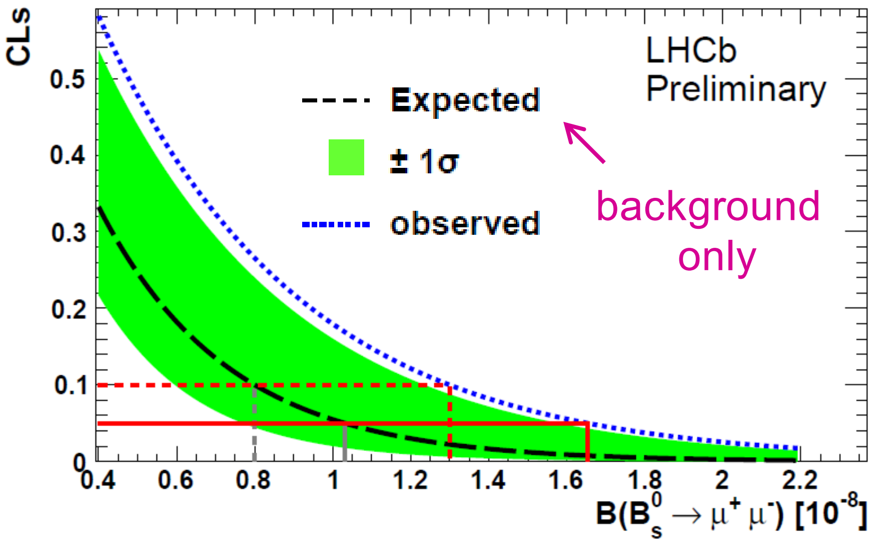
	BDT<0.25	0.25<BDT<0.5	0.5<BDT<0.75	0.75<BDT
Exp.combinatorial	2968 ± 69	25 ± 2.5	2.99 ± 0.89	0.66 ± 0.40
Exp. SM signal	1.26 ± 0.13	0.61 ± 0.06	0.67 ± 0.07	0.72 ± 0.07
Observed	2872	26	3	2

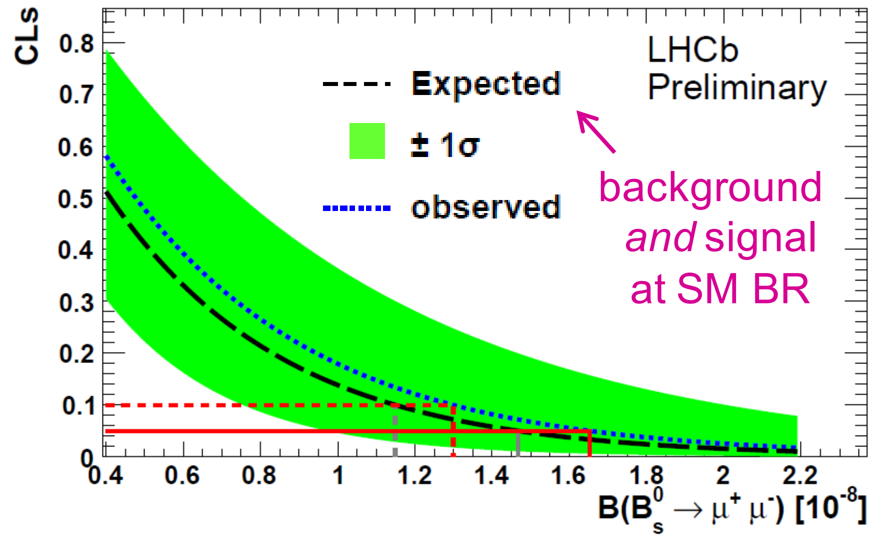


$m_{\mu\mu} = 5.357$ GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for $p_T > 0.5$ GeV

LHCb preliminary limit (stat + syst) on BR($B_s \rightarrow \mu^+\mu^-$)

Compute limits using frequentist CLs method and LHCb combined result for f_s/f_d





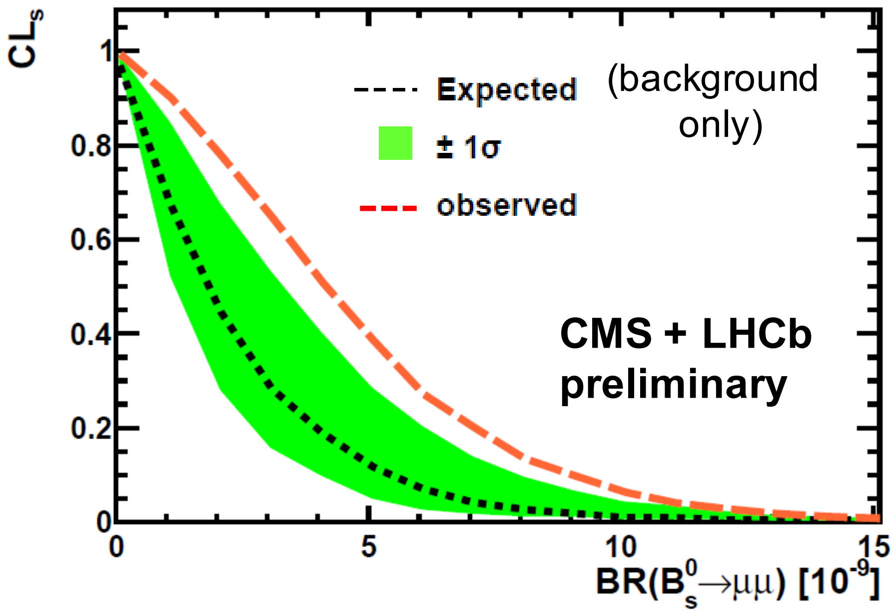
LHCb-CONF-2011-037

	Background only	Background + SM signal
Expected limit at 95% (90%) C.L.	1.0 (0.8) x 10^{-8}	1.5 (1.2) x 10^{-8}
Observed limit at 95% (90%) C.L.	1.6 (1.3) x 10^{-8}	
p-value of bckgd only hypothesis	14%	
Observed limit at 95% (90%) C.L. when combined with 2010 result	$\boxed{1.5 (1.2) \times 10^{-8}}$	

Preliminary BR($B_s \to \mu^+\mu^-$) combination

new today!

A preliminary CMS-LHCb combination on BR($B_s \to \mu^+\mu^-$) has been performed, again using the CLs approach, & taking LHCb value of f_s/f_d as common input



Observed limit at 95% (90%): 1.1 (0.9) x 10^{-8}

This is 3.4 times the expected SM value

A BR of 1.8 x 10^{-8} has a CLs value of ~0.3%

Conclusions

LHC flavour physics has come very far, very quickly:

- comprehensive series of clean measurements performed over a wide range of topics
- B-factory & Tevatron sensitivity overtaken or matched in many benchmark analyses
- broad flavour programme of LHCb now augmented by CMS in $B_s \to \mu^+\mu^-$ search

No sign of discrepancies with the SM yet:

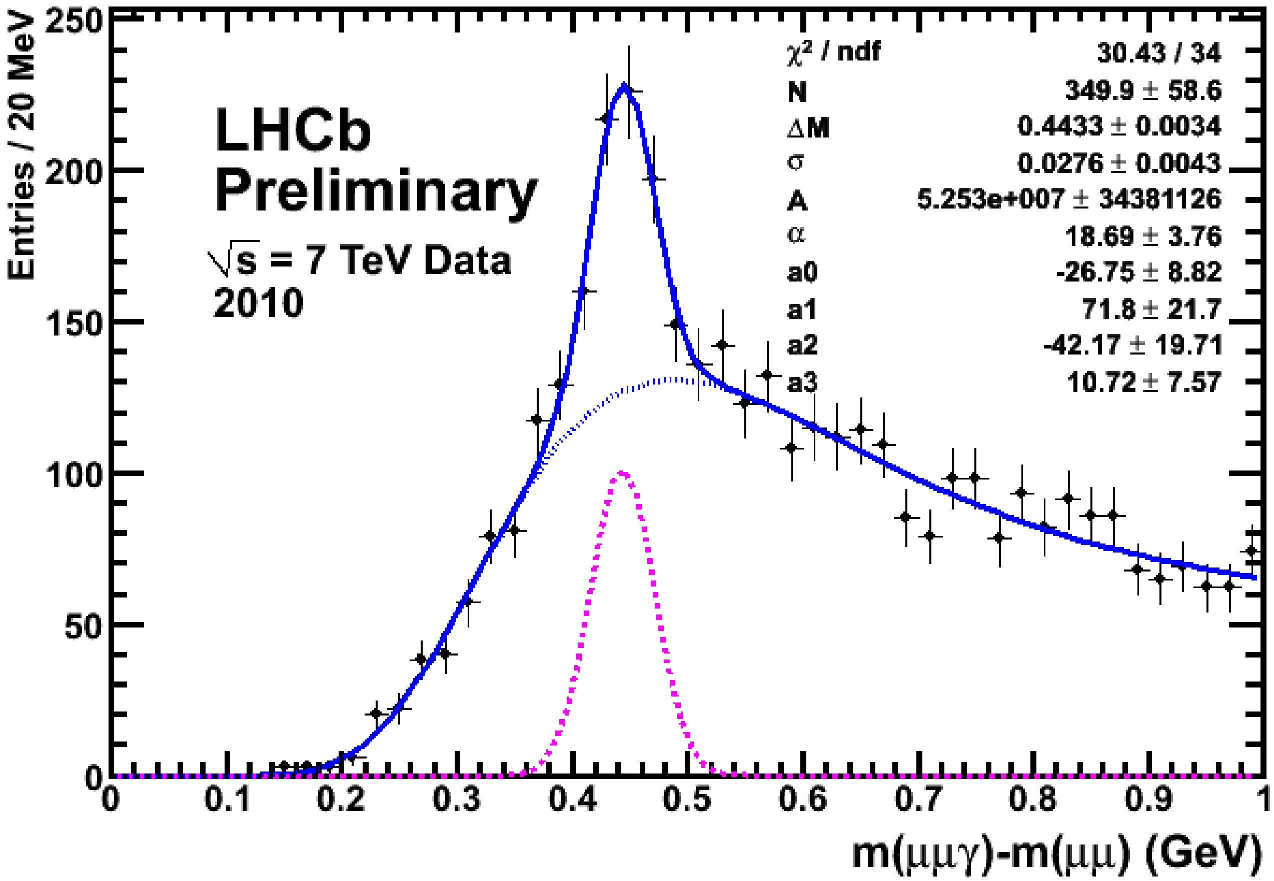
- but flavour observables do have excellent sensitivity to New Physics contributions!
- much higher precision expected over next ~5 years...
- ...and beyond: LHCb upgrade →

LHC has become the flavour frontier, and will remain so for a long time to come

Many thanks to all who contributed material and advice for this presentation !

Backups

χ_b at LHCb

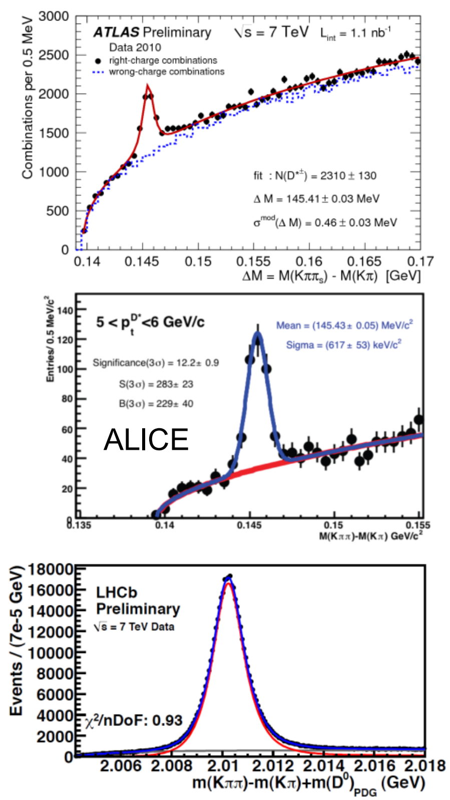


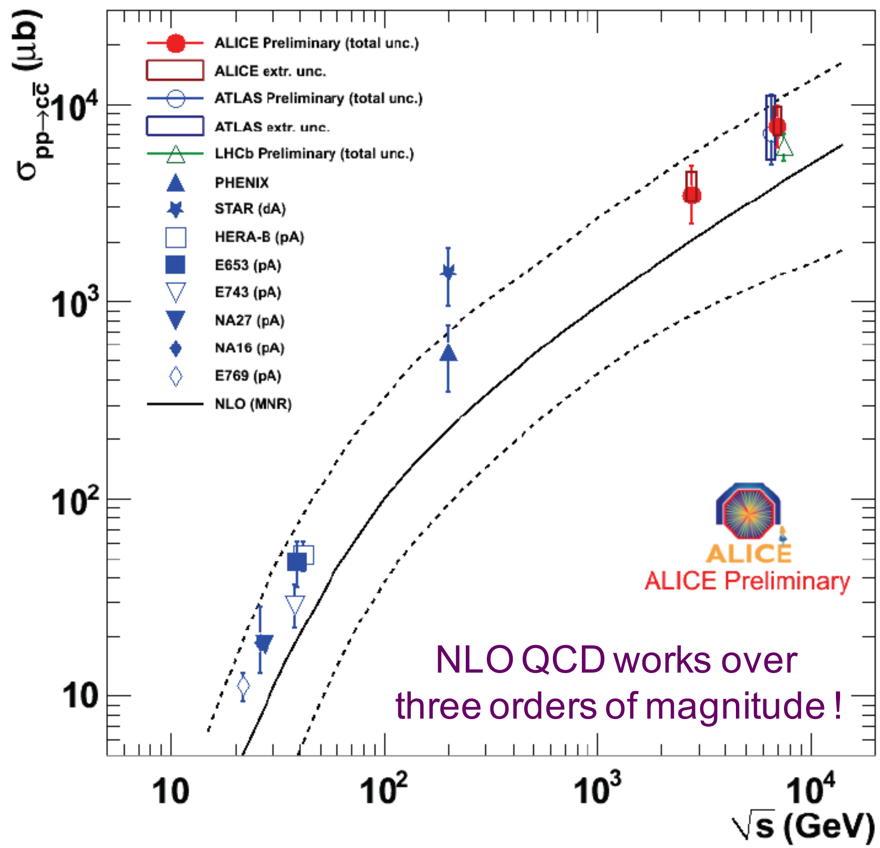
LHCb
Preliminary
√s = 7 TeV Data
2010
χ² / ndf 30.43 / 34
N 349.9 ± 58.6
ΔM 0.4433 ± 0.0034
σ 0.0276 ± 0.0043
A 5.253e+007 ± 34381126
α 18.69 ± 3.76
a0 -26.75 ± 8.82
a1 71.8 ± 21.7
a2 -42.17 ± 19.71
a3 10.72 ± 7.57
Entries / 20 MeV
0
50
100
150
200
250
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
m(μμγ)-m(μμ) (GeV)

Open charm production

Preliminary results on open charm cross-section exist from ALICE, ATLAS & LHCb

'Δm peak' in $D^* \to D(K\pi)\pi$





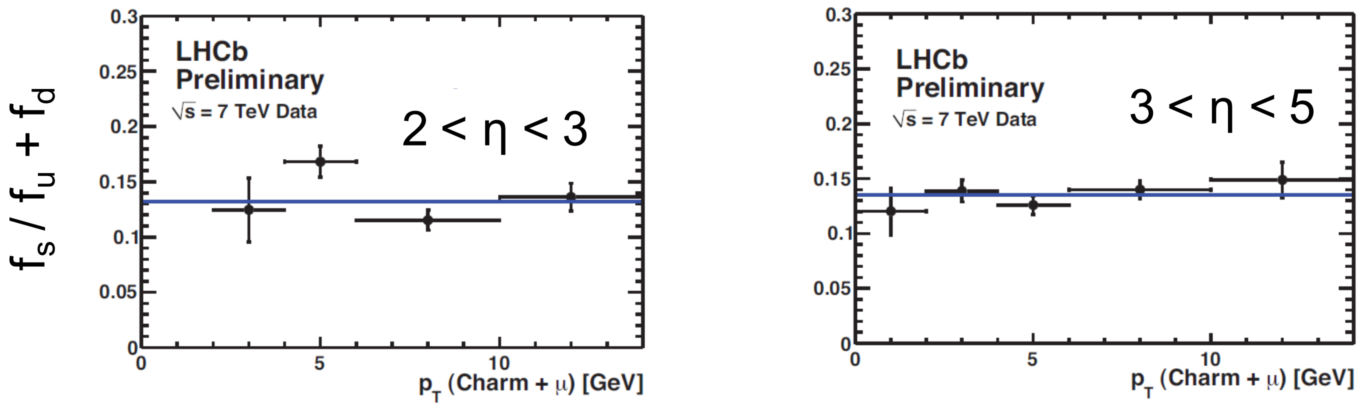
ALICE, A. Dainese, Quark Matter 2011
ATLAS-CONF-2011-017
LHCb-CONF-2010-013

Open charm cross-section at $\sqrt{s}$ = 7 TeV ~6.5 mb - good news for flavour physics!

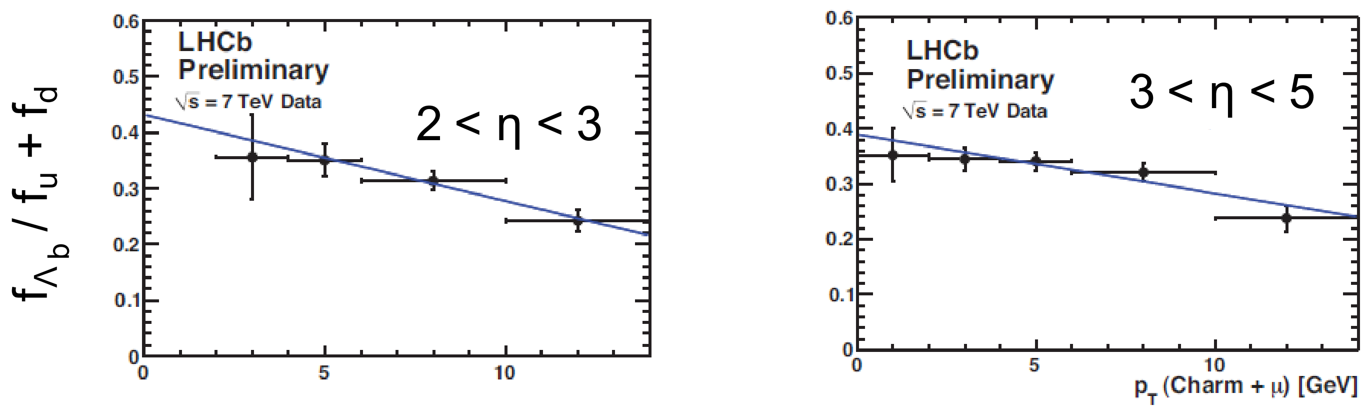
Dependence on p_T ?

In semileptonic analysis study whether fragmentation fractions vary with η and p_T.

No dependence is seen in f_s/f_d (here plotted as $f_s/[f_d+f_u]$):



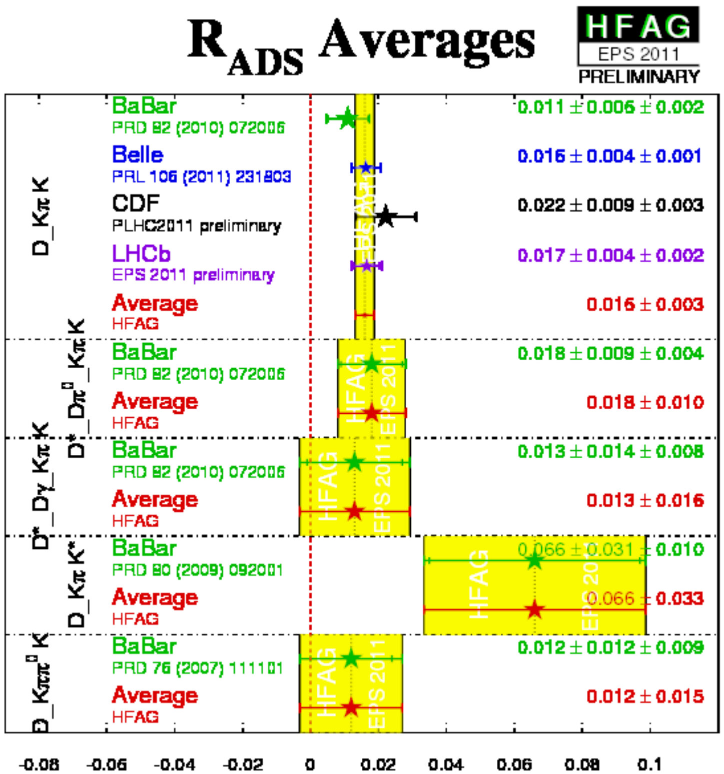
However, there *is* an indication of significant p_T dependence in Λ_b fraction:

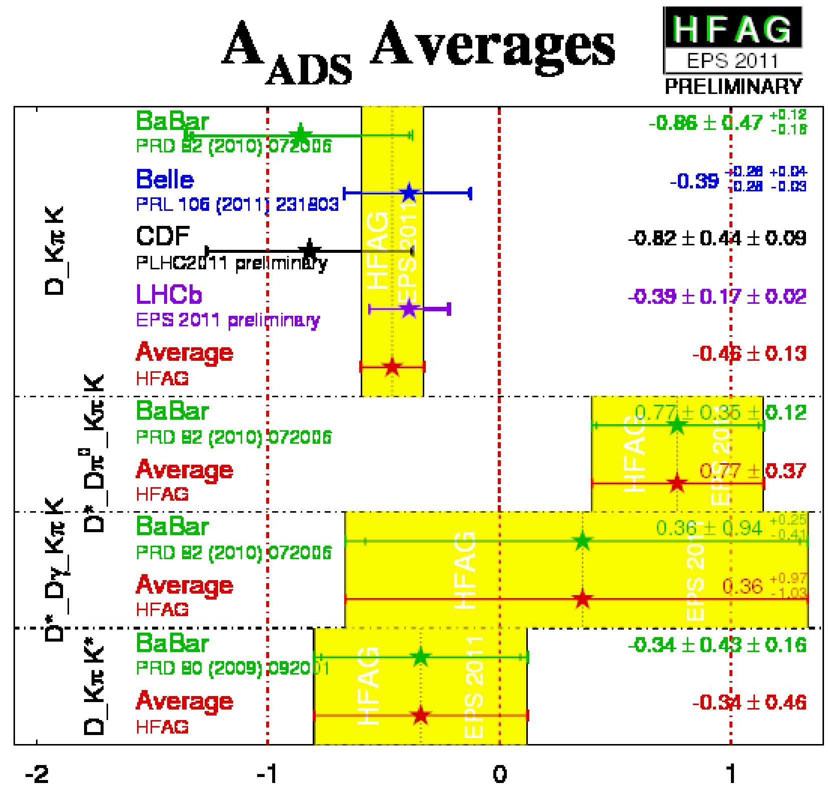


Upcoming results to watch out for: measurement of production asymmetries!

LHCb-CONF-2011-028

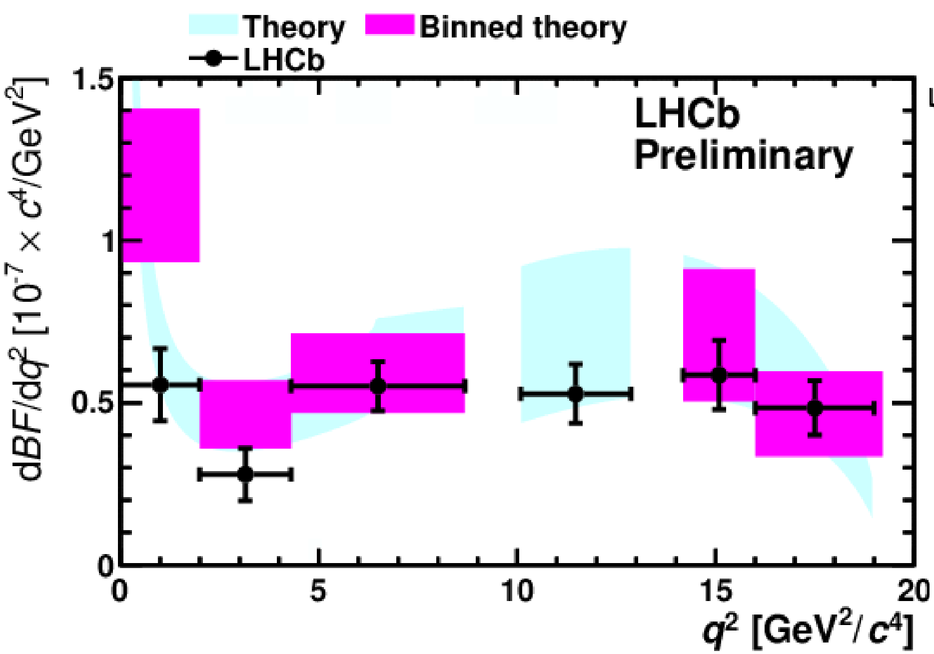
LHCb ADS analysis results in context

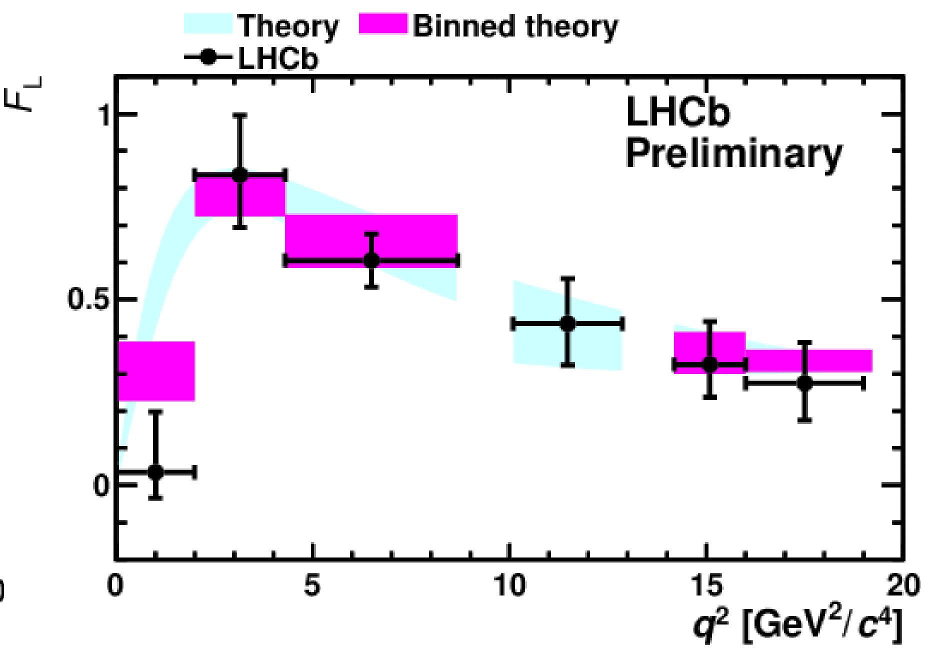




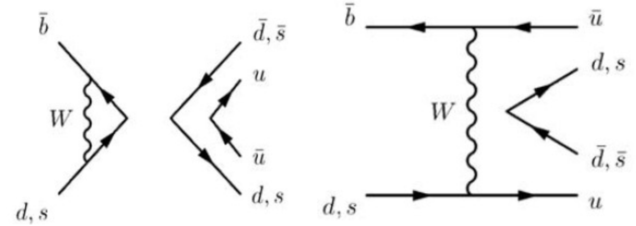
$d\Gamma/dq^2$ and F_L in $B^0 \to K^*\mu^+\mu^-$

These observables have good consistency with the SM expectations !



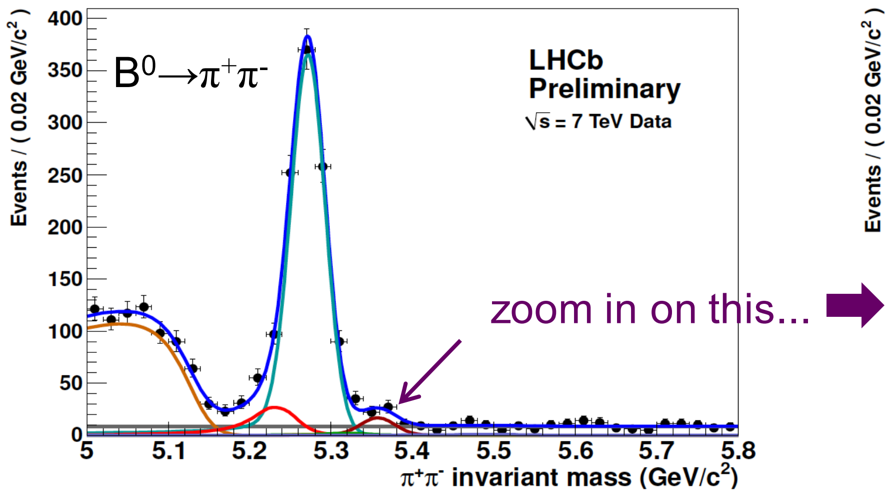


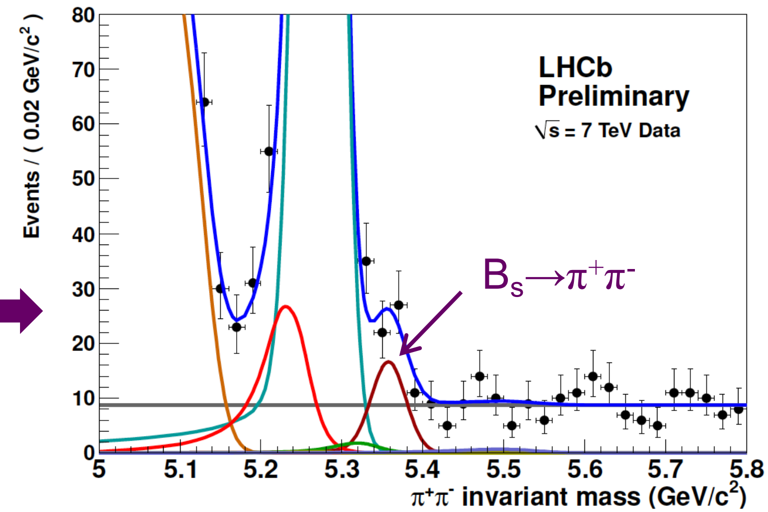
Search for $B_s \to \pi^+\pi^-$



Possible contribution of suppressed diagrams, e.g. penguin annihilation, complicates extraction of weak phase info from B→hh decays.

To learn more, look for decays where only suppressed amplitudes contribute, for example $B_s \to \pi^+\pi^-$. Deploy tight selection:





[LHCb-CONF-2011-042]

Signal observed with 5.2σ significance – this is a first observation

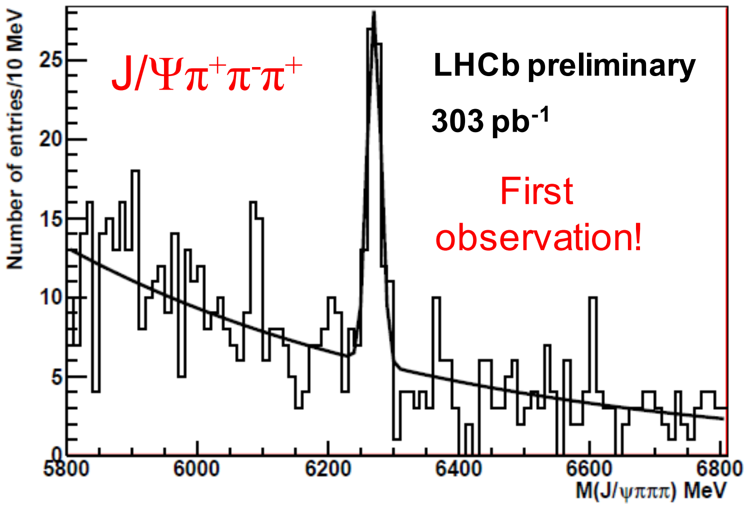
$$\mathcal{BR}(B_s^0 \to \pi^+\pi^-) = (0.98^{+0.23}_{-0.19}(\text{stat}) \pm 0.11(\text{syst})) \times 10^{-6}$$

Consistent with CDF preliminary result: $0.57 \pm 0.15 \pm 0.10 \times 10^{-6}$ [CDF-note-10498]

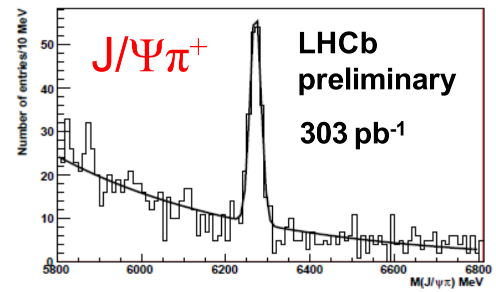
Observation of $B_c \to J/\Psi\pi\pi\pi$

[LHCb-CONF-2011-040]

Until now, only observed B_c decay modes were $J/\Psi\mu\nu$ and $J/\Psi\pi$.

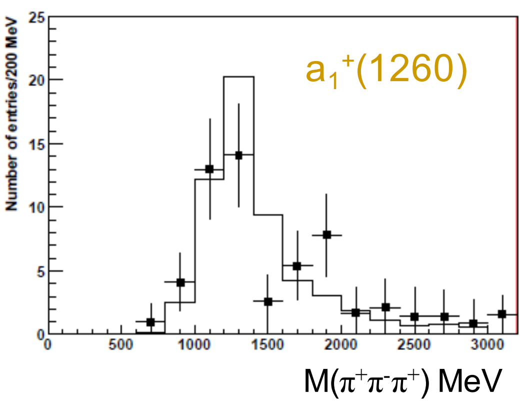


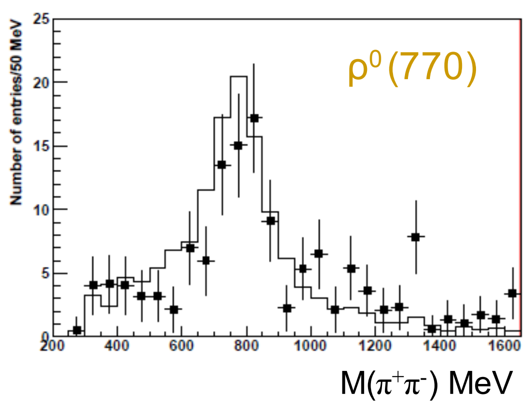
Measure relative BR w.r.t. $J/\Psi\pi^+$:

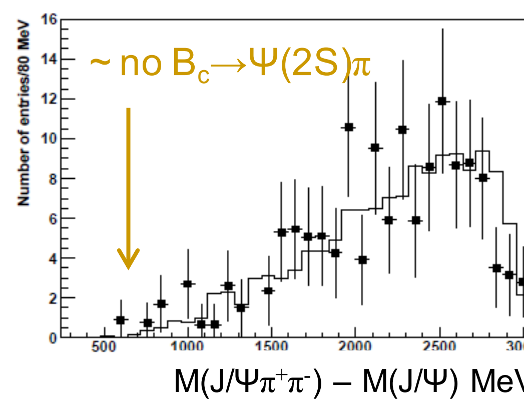


$$\frac{BR(B_c \to J/\Psi\pi^+\pi^-\pi^+)}{BR(B_c \to J/\Psi\pi^+)} = 3.0 \pm 0.6 \pm 0.4$$

Compare background subtracted data
mass projections with MC with $B_c \to J/\Psi a_1(1260)$, $a_1(1260) \to \rho^0\pi$, $\rho^0 \to \pi\pi$





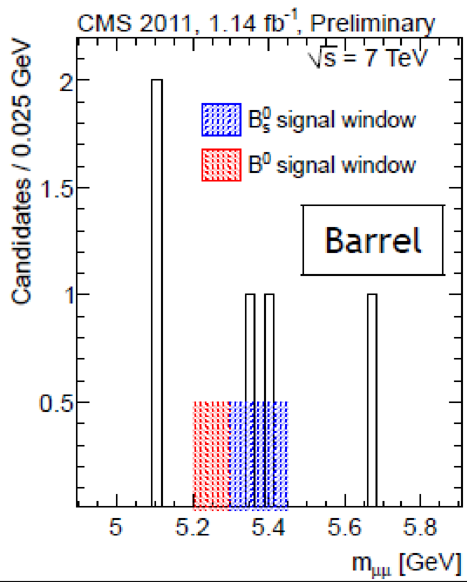


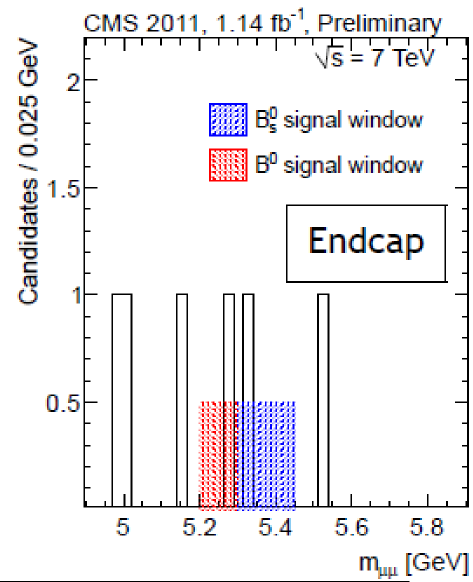
CMS $B_{d,s} \rightarrow \mu\mu$ results

	Barrel		Endcap	
	$B^0 \to \mu^+\mu^-$	$B_s^0 \to \mu^+\mu^-$	$B^0 \to \mu^+\mu^-$	$B_s^0 \to \mu^+\mu^-$
Acceptance	$(24.62 \pm 0.99) \times 10^{-2}$	$(24.72 \pm 0.99) \times 10^{-2}$	$(22.61 \pm 0.91) \times 10^{-2}$	$(23.14 \pm 0.93) \times 10^{-2}$
$\varepsilon_{\text{analysis}}$	$(2.23 \pm 0.19) \times 10^{-2}$	$(2.22 \pm 0.19) \times 10^{-2}$	$(1.16 \pm 0.10) \times 10^{-2}$	$(1.24 \pm 0.11) \times 10^{-2}$
ε_{tot}	$(0.36 \pm 0.04) \times 10^{-2}$	$(0.36 \pm 0.04) \times 10^{-2}$	$(0.21 \pm 0.02) \times 10^{-2}$	$(0.21 \pm 0.02) \times 10^{-2}$
$N_{\text{signal}}^{\text{exp}}$	0.065 ± 0.011	0.80 ± 0.16	0.025 ± 0.004	0.36 ± 0.07
$N_{\text{bg}}^{\text{exp}}$	0.40 ± 0.23	0.60 ± 0.35	0.53 ± 0.27	0.80 ± 0.40
$N_{\text{peak}}^{\text{exp}}$	0.25 ± 0.06	0.07 ± 0.02	0.16 ± 0.04	0.04 ± 0.01
N_{obs}	0	2	1	1

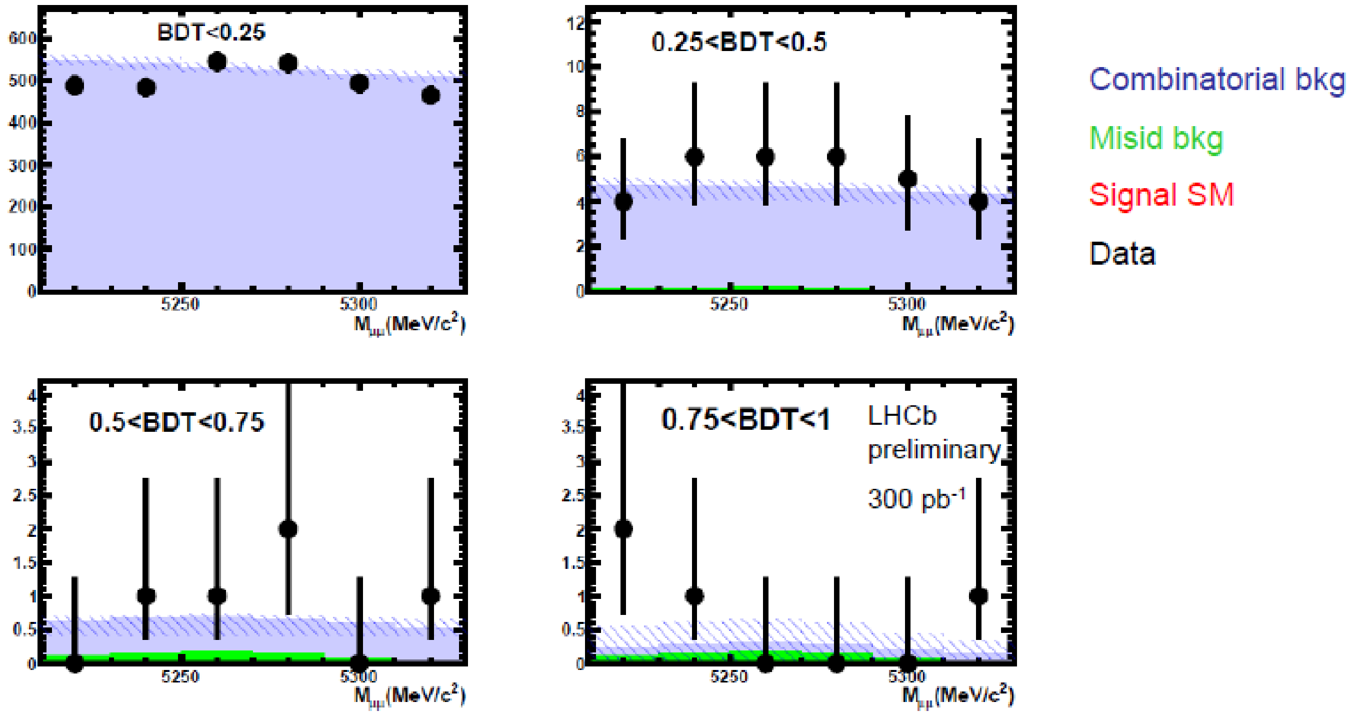
- As expected
  - ▹ based on sidebands
  - ▹ studied with $I < 0.7$
  - → no evidence for anomalous signal
- Expected UL (median)

  $B_s^0 \to \mu^+\mu^- : 1.8 \times 10^{-9}$



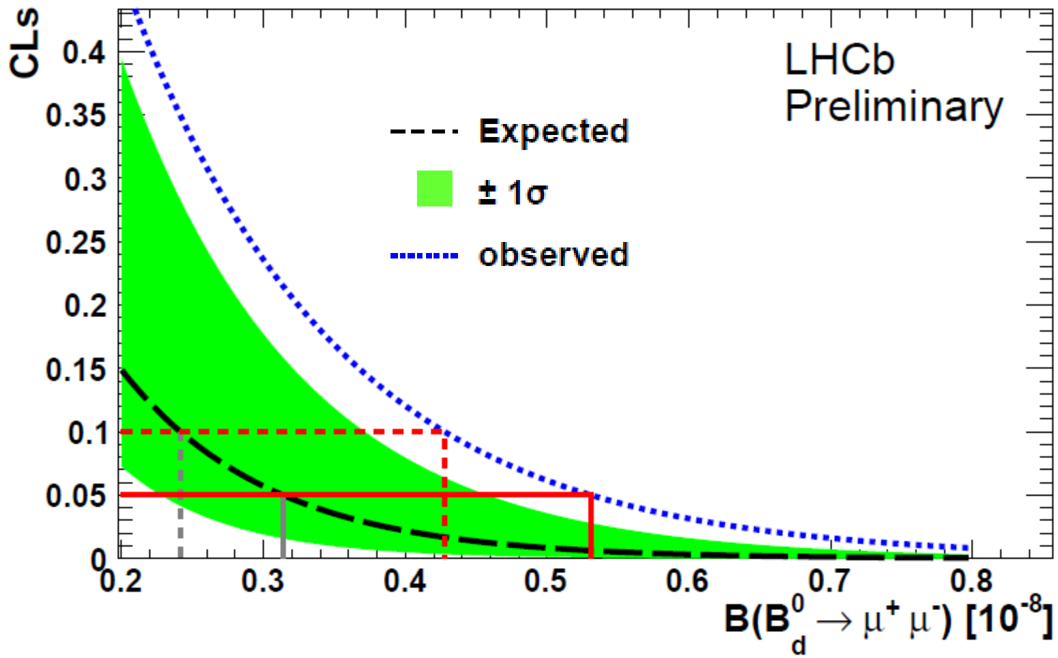


LHCb $B^0_d \to \mu\mu$ results (2011, 300 pb^{-1})



	BDT<0.25	0.25<BDT<0.5	0.5<BDT<0.75	0.75<BDT
Exp.combinatorial	3175 ± 72	26.6 ± 2.5	3.1 ± 0.8	0.7 ± 0.4
Exp. MisID	0.6± 0.1	0.6± 0.1	0.6± 0.1	0.6± 0.1
Observed	3025	31	5	4

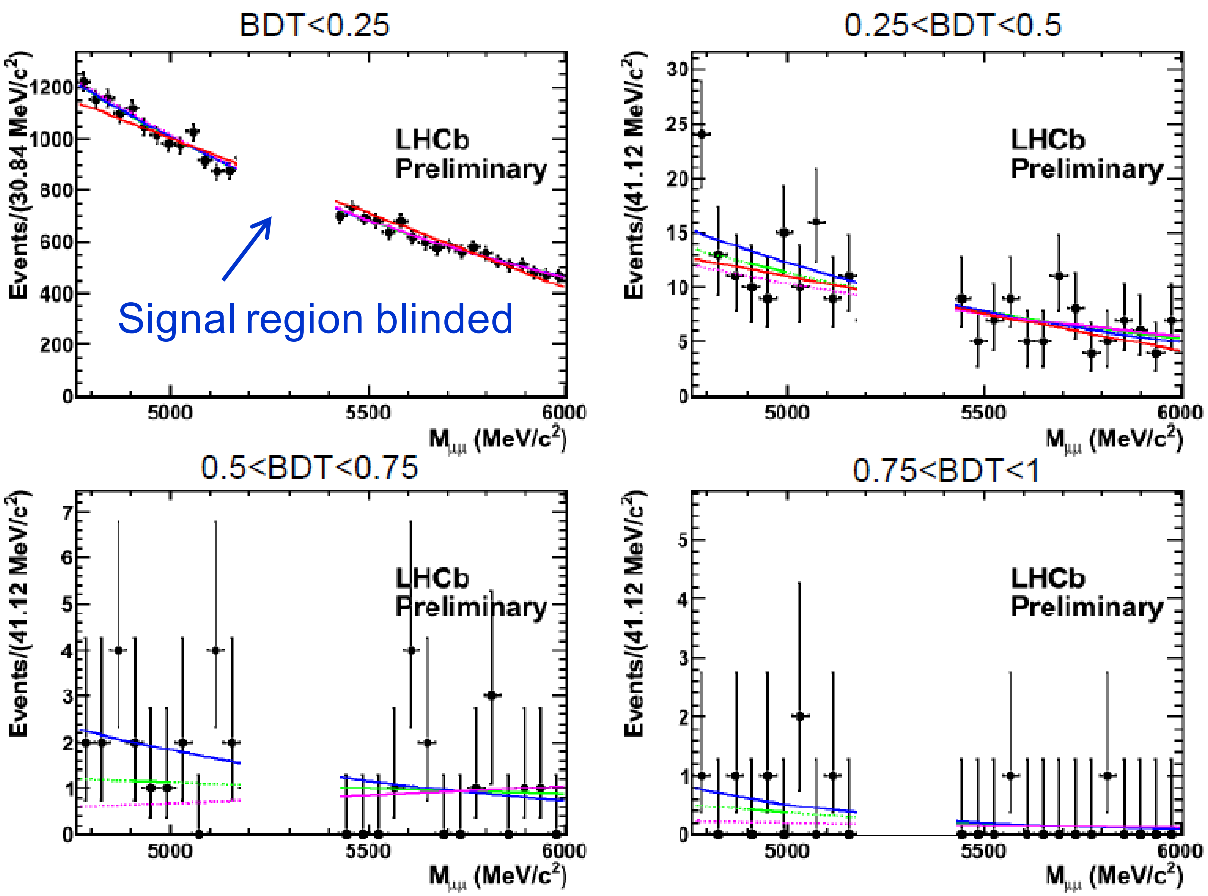
LHCb $B^0_d \to \mu\mu$ results (2011, 300 pb^{-1})



	Bkg only 90(95) %CL	CLb
Expected stat+syst	2.4 (3.1) $\times 10^{-9}$	
Observed stat+syst	4.2 (5.2) $\times 10^{-9}$	0.90

Background description vs $M_{\mu\mu}$ in LHCb

Different parameterisations performed for background shape → systematics



Limits on BR($B_d \to \mu^+\mu^-$)

No significant excess seen in $B_d \to \mu^+\mu^-$ search

95% (90%) C.L. limits

CMS observed	$\boxed{4.6\ (3.7) \times 10^{-9}}$
CMS expected	4.8×10^{-9}
LHCb expected	$3.1\ (2.4) \times 10^{-9}$
LHCb observed	$\boxed{5.2\ (4.2) \times 10^{-9}}$

(NB here LHCb results are 2011 data only)

$B_s \to \mu^+\mu^-$ – extrapolations performed from 2010 LHCb analysis