Heavy Flavour Results at the LHC

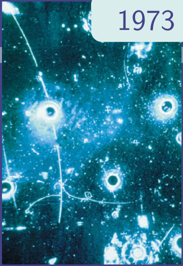
- Introduction
- Flavour at the LHC
- Short presentation of LHCb
- Selected Cross-Section measurements
- Charm Physics
- b physics focusing on b$\rightarrow$s transitions

30 August 2011
Physics in Collision, Vancouver

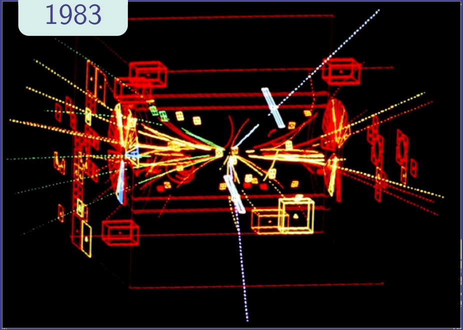
Patrick Koppenburg
on behalf of the LHCb Collaboration
including ATLAS, CMS, ALICE results

Indirect Searches

- Sensitive to New Physics effects
  - When was the Z discovered?
    - 1973 from $N\nu \to N\nu$?
    - 1983 at SpS collider?
  - c quark postulated by GIM, third family by Kobayashi & Maskawa



1973



1983

Indirect Searches

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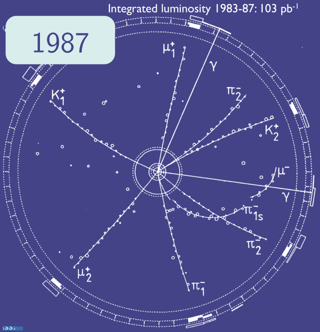
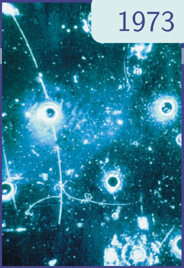
  - When was the Z discovered?
    - 1973 from $N\nu \to N\nu$?
    - 1983 at SpS collider?
  - c quark postulated by GIM, third family by Kobayashi & Maskawa
- ✔ Estimate masses
  - t quark from $B\overline{B}$ mixing
  - ✔ Much larger mass coverage than $\sqrt{s}$
- ✔ Get phases of couplings
  - Half of new parameters
  - Needed for a full understanding
- Look in lepton and **flavour** sectors
  - ➜ CP asymmetry in the Universe



INDIRECT SEARCHES

1973



The b an c quarks are the best laboratory for this programme

Hot channels for the near future:

$B_s \to \mu\mu$: Is there susy? $\mathcal{B} \propto \frac{\tan^6 \beta}{m_A^4}$.

$B_s \to J/\psi\phi$: Beyond-SM CPV?

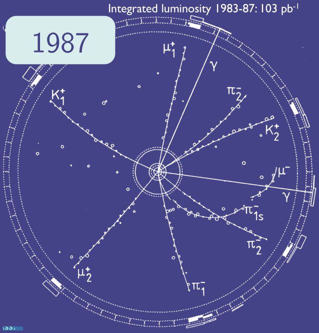
$B_d \to \mu\mu K^*$: Right-handed currents?

γ (ϕ_3): Is the CKM matrix sufficient?

y_{cp}: Beyond-SM CPV in charm?

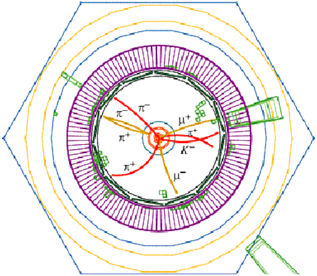
I'll present new results in these areas!

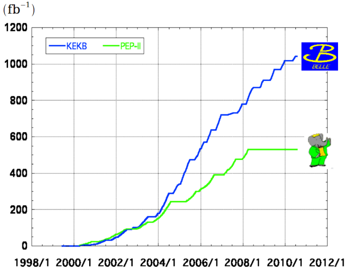
1987



Flavour at the LHC

- It was the reign of the B factories
  - ✔ Clean events
  - ✔ More than 10^9 $B\overline{B}$ pairs
- ... and of the Tevatron





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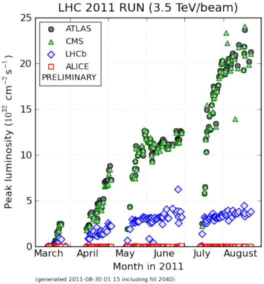
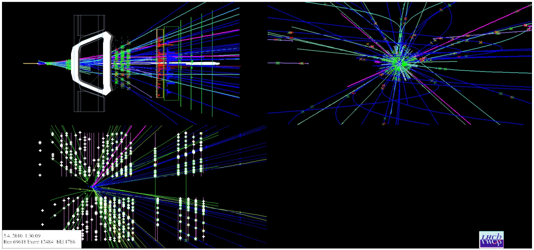
- Now are the times of the LHC
  - Luminosity constantly growing
  - $\sigma_{b\bar{b}} \sim 300\,\mu\mathrm{b} \rightarrow > 10^{12}$ $b\bar{b}$ pairs produced so far
  - ✗ But events are busy
- Can we get them clean?





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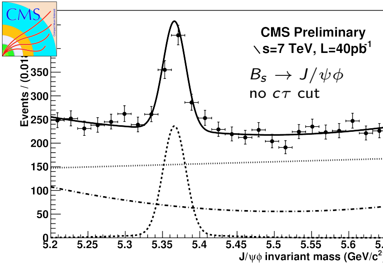
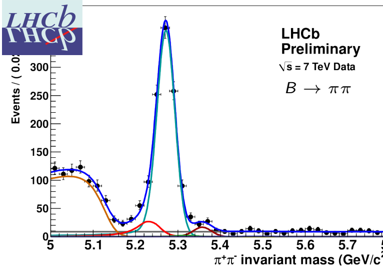
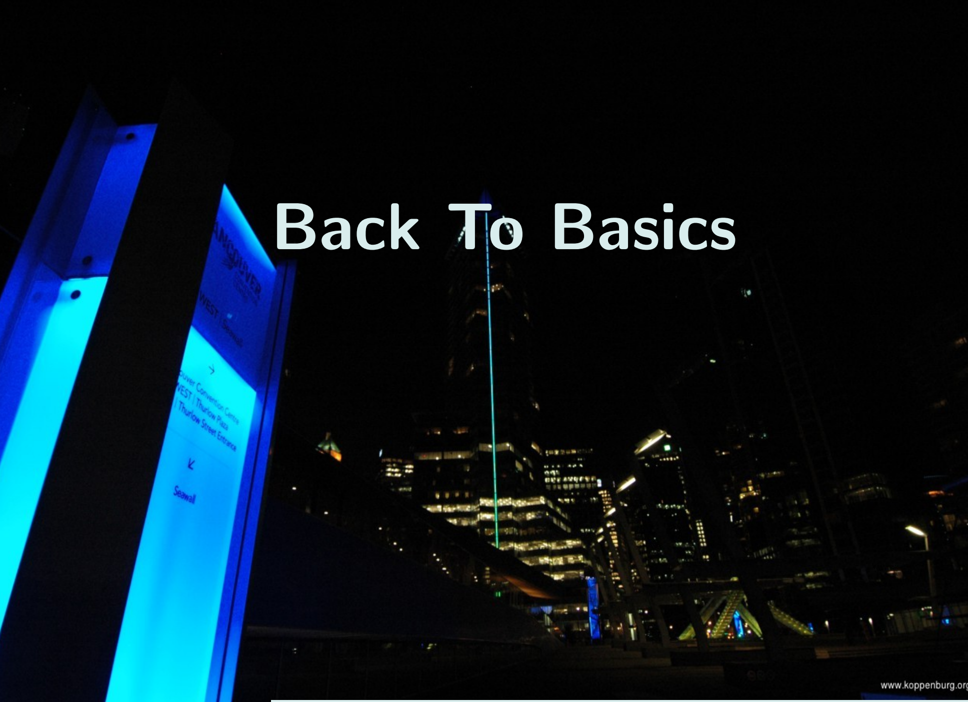
  - ✗ But events are busy
- Can we get them clean?
  - ✔ You bet we can!

Like flavour? Come to the LHC!





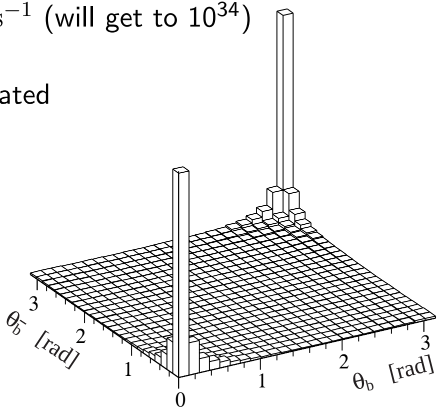
Back To Basics



LHC

Nominal LHC Environment

- *pp* collider at 7 TeV (will be 14)
  - Inelastic cross-section about 60 mb
  - $b\bar{b}$ cross-section about 300 μb (one every 200)
- Bunch crossings at 20 MHz (will be 40)
- Luminosity up to $2 \cdot 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (will get to 10^{34})
  - ➜ 10^6 $b\bar{b}$ pairs per second
- Direction of b and $\bar{b}$ very correlated
  - ➜ A 4π coverage not optimal
  - ➜ Build a forward spectrometer
- The choice of the LHCb collaboration
  - ➜ $\sim$ 75 μb in LHCb and Atlas/CMS acceptances



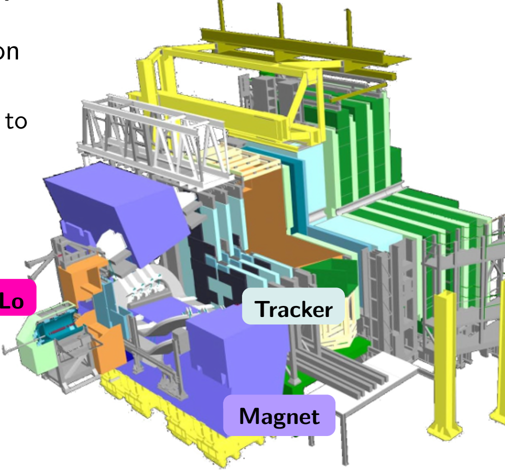
LHCb Detector

Forward detector (b-hadrons produced forward at LHC)

- Warm dipole magnet. Polarity can be reversed.

✔ Good momentum and position resolution

  - Vertex detector gets 8mm to the beam



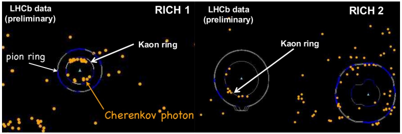
LHCb Detector & performance

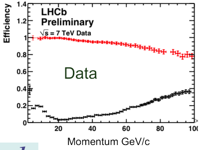
Forward detector (b-hadrons produced forward at LHC)

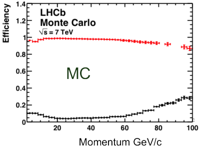
- Warm dipole magnet. Polarity can be reversed.

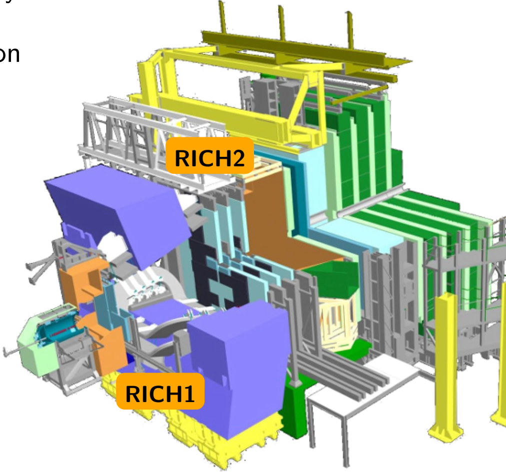
✔ Good momentum and position resolution

✔ Excellent Particle ID









LHCb Trigger

Forward detector (b-hadrons produced forward at LHC)

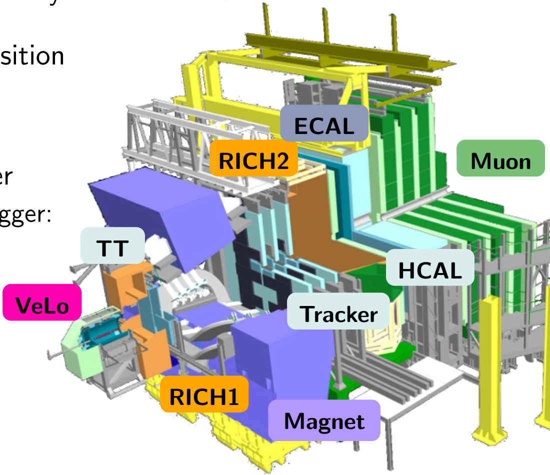
- Warm dipole magnet. Polarity can be reversed.

✔ Good momentum and position resolution

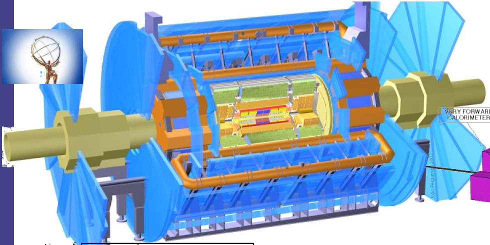
✔ Excellent Particle ID

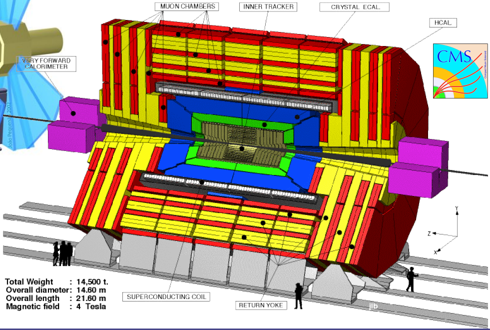
✔ Versatile two stage trigger

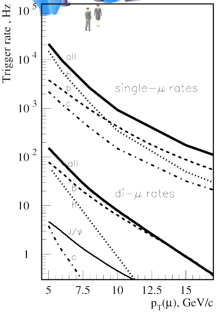
  - Hardware-based L0 trigger: moderate p_T cuts ➜ 800 kHz
  - Whole data sent to trigger farm
  - 3 kHz output rate



Atlas and CMS



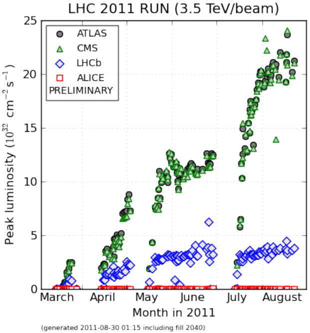


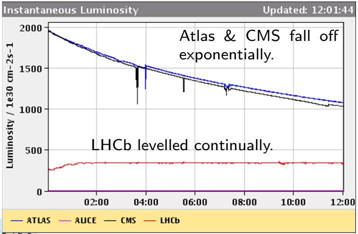


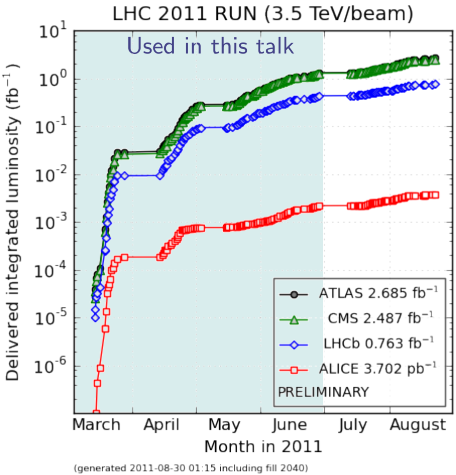
- General purpose detectors with a *b* physics programme
- High trigger efficiency on muon channels
  - But with high p_T cut

LUMINOSITY IN 2011

[Lumi Plots]







90–95% was recorded as quality data.

Cross-Sections

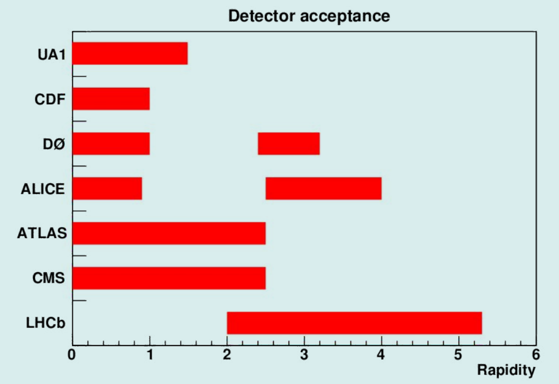
- LHCb is the forward detector at the LHC
  - ✔ Unique rapidity coverage
- K_S^0 cross section
- $\Lambda/\overline{\Lambda}$ and $p/\overline{p}$

✔ Open charm

✔ J/ψ

✔ B

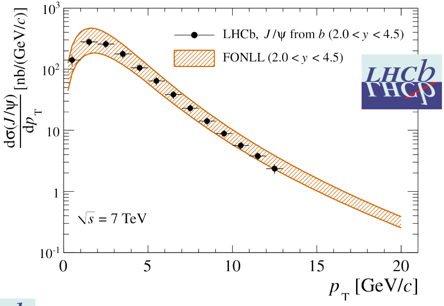
- Z, W ...

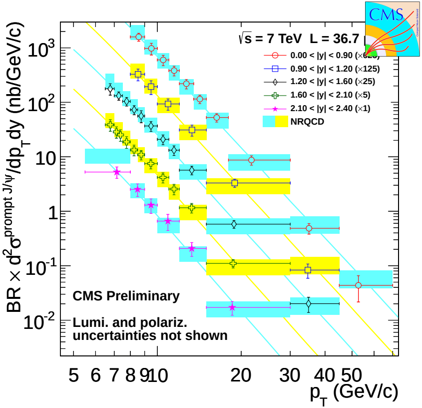


This is the tracking acceptance.
For composites LHCb gets even higher.

J/ψ CROSS SECTION

Prompt J/ψ cross-section has been measured by LHCb [Eur. Phys. J. C 71 (2011) 1645.] CMS [BPH10014] Atlas [Nucl.Phys. B850 (2011) 387-444] Alice [arXiv:1105.0380]





Measurements getting more precise than theory — modulo polarisation to be measured.

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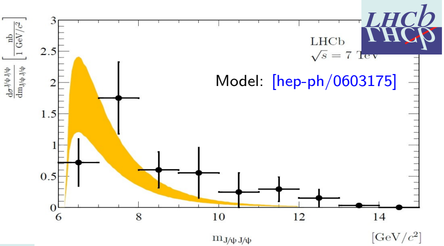
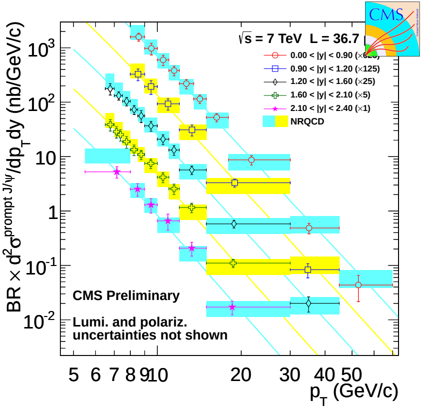
LHCb also measures the double J/ψ cross section: [LHCb-CONF-2011-009]

$$5.1 \pm 1.0 \pm 1.1\,\mathrm{nb}^{-1}$$



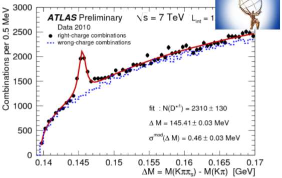


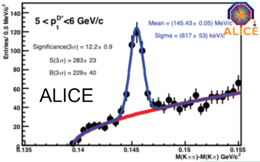
Measurements getting more precise than theory — modulo polarisation to be measured.

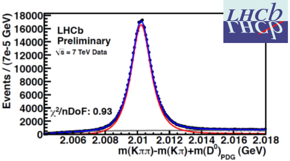
Charm

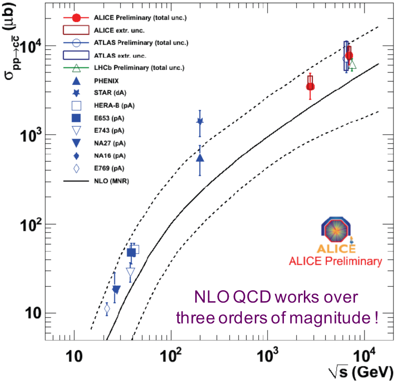
Open charm cross section

'Δm peak' in $D^* \to D(K\pi)\pi$









Charm cross section measurements from Alice, Atlas [ATLAS-CONF-2011-017] and LHCb [LHCb-CONF-2011-013]

The open charm cross section at 7 TeV is $\sim$ 6.5 mb ➜ good prospects for flavour physics

Charm Mixing

See Eunil Won

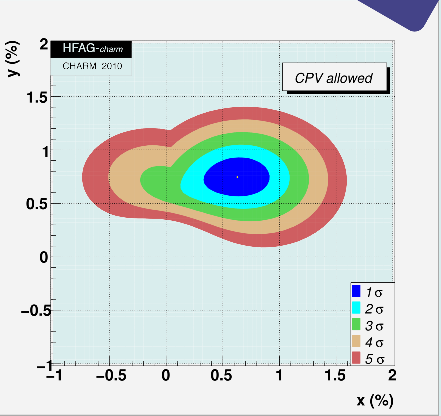
$$D_{1,2} = p\left|D^0\right\rangle \pm q\left|\overline{D}^0\right\rangle$$

$$x = \frac{m_2 - m_1}{2\Gamma} \quad y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$$

The mixing parameters are small ($\mathcal{O}(1\%)$)

- HFAG average more than 5σ away from zero [HFAG]
- No single measurement excludes 0

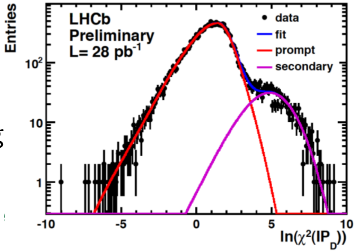
➜ Measure



$$y_{\mathrm{CP}} = \frac{\hat{\Gamma}(D^0 \to K^+K^-)}{\hat{\Gamma}(D^0 \to K^-\pi^+)} - 1 = y\cos\phi - x\sin\phi\left(\frac{A_m}{2} + A_{\mathrm{prod}}\right)$$

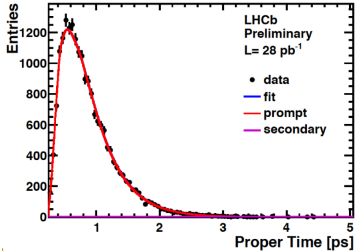
y_{CP}

- Use $D^* \to D^0\pi$: Separate prompt and non-prompt using impact parameter
- Lifetime acceptance obtained on an event-by-event basis in data by varying the lifetime an re-running the trigger



Measure

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



Preliminary result on 2010 data:

[LHCB-CONF-2011-054]

$$y_{\mathrm{CP}} = (-0.55 \pm 0.63 \pm 0.41)\,\%$$

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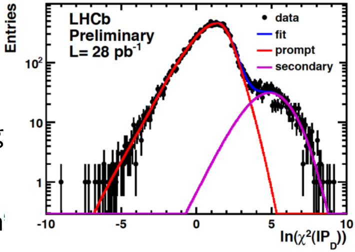
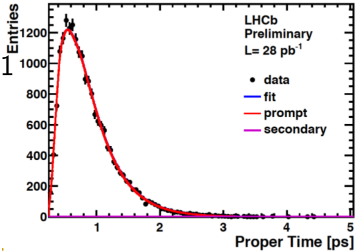


A good way to look for CP violation in charm mixing is to search for a non-zero asymmetry in

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^+K^-) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^+K^-) + \tau(D^0 \to K^+K^-)} - 1$$



Preliminary result on 2010 data:

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

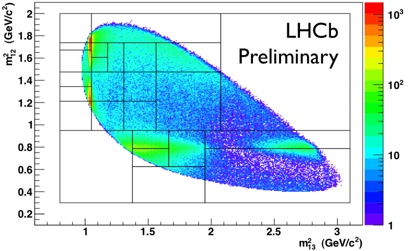
$$y_{CP} = (-0.55 \pm 0.63 \pm 0.41)\,\%$$
$$A_\Gamma = (-0.59 \pm 0.59 \pm 0.21)\,\%$$

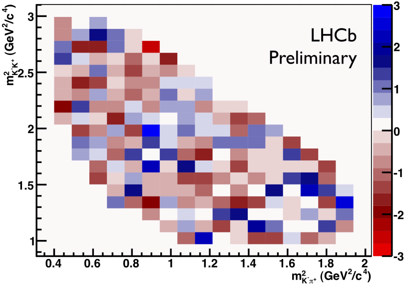
Direct CP violation

Perform model independent binned CP violation search in Cabibbo-suppressed $D^+ \to K^+K^-\pi$ decays

1. 370 000 events (Babar has 43k)
2. Normalise D^+ and D^- to remove production asymmetries
3. Try several binnings (uniform or resonance-motivated)
4. Look for fake CP violation in control modes and sidebands

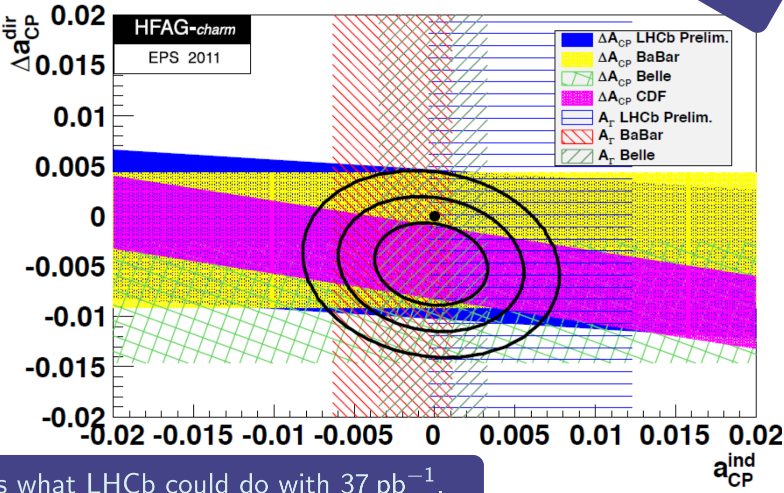
→ No evidence of CP violation. Paper in preparation.





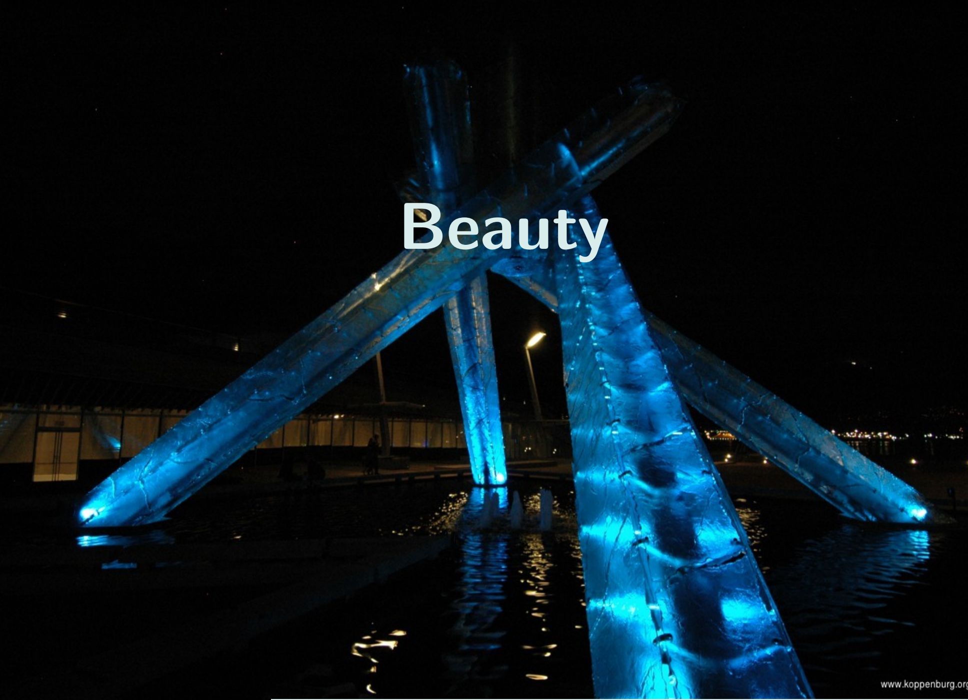
LHCb and Charm

See Eunil Won



That's what LHCb could do with 37 pb^{-1}.
Now we have 700 pb^{-1}.

Beauty

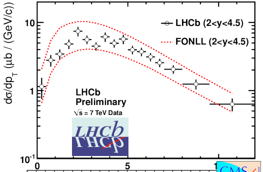


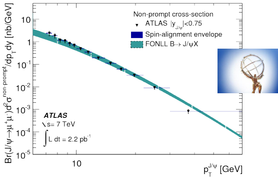
b PRODUCTION

DETACHED J/ψ

CMS: [Eur.Phys.J. C71 (2011) 1575],
Atlas: [Nucl.Phys. B850 (2011) 387-444]
LHCb: [Eur. Phys. J. C 71 (2011) 1645]

$$\sigma^{4\pi}_{b\bar{b}} = (288 \pm 4 \pm 48)\ \mu\text{b}$$





DILEPTON TAGS

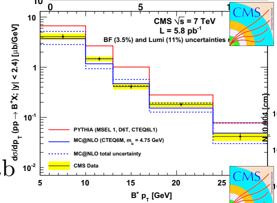
CMS: [CMS-PAS-BPH-10-015]

$D\mu$ TAGS

LHCb: [Physics Letters B 698 (2011) 14]

$$\sigma^{(2<\eta<6)}_{b\bar{b}} = (75 \pm 5 \pm 13)\ \mu\text{b}$$

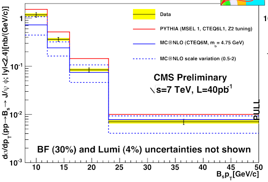
$$\sigma^{4\pi}_{b\bar{b}} = (284 \pm 20 \pm 49)\ \mu\text{b}$$

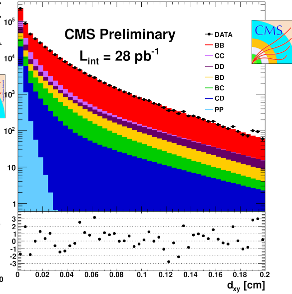


FULLY RECONSTRUCTED

$B \to J/\psi X$

LHCb [CONF-2011-033]
CMS: [Phys.Rev.Lett.106:112001,2011]
[Phys. Rev. Lett. 106, 252001 (2011)]
[arXiv:1106.4048]





b FRAGMENTATION f_s/f_d

35 pb^{-1}

Fraction of $b \to B_s X$ is an essential ingredient for $B_s \to \mu\mu$ and other rare decays

- LHCb has measured it in 2 ways
  - Ratio of $B \to D_s \mu X$ to $B \to D^+ \mu X$ modes [LHCb-CONF-2011-028]
  - Ratio of $B_d \to DK$ and $B_s \to D_s \pi$ modes [Accepted by PRL]

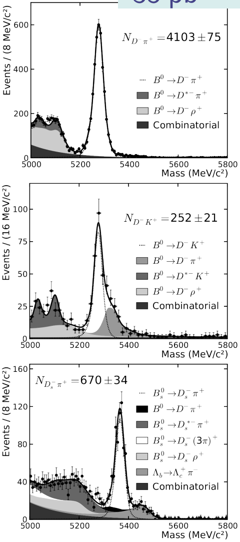
➜ Combination [LHCb-CONF-2011-034]

$$\left(\frac{f_s}{f_d}\right)_{\text{LHCb}} = 0.267 \,{}^{+\,0.021}_{-\,0.020}$$

- Similar to LEP and Tevatron result

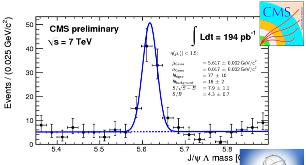
$$\left(\frac{f_s}{f_d}\right)_{\text{LEP, Tevatron}} = 0.271 \pm 0.027$$

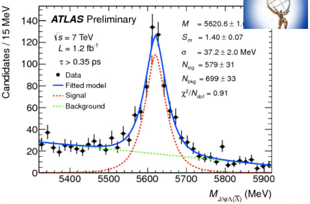
Although there's no reason they should be the same



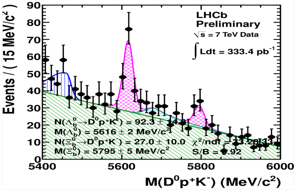
b-Baryons

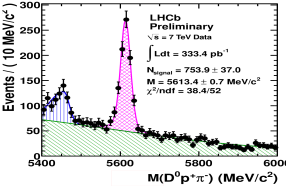
See Rob Harr

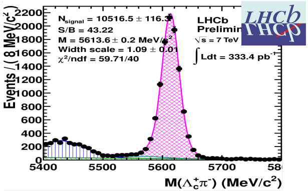




- b-baryons are also seen by all experiments
  - Atlas, CMS, LHCb see $\Lambda_b \to J/\psi\Lambda$ [ATLAS-CONF-2011-124] [CMS-DP-2011-007] [LHCb-CONF-2011-001]
    - LHCb: $\tau_{\Lambda_b} = 1.353 \pm 0.108 \pm 0.035$
  - LHCb sees $\Lambda_b \to \Lambda_c\pi$, $\Lambda_b \to D^0 p\pi$, $\Lambda_b \to D^0 pK$ (can be used to measure γ) and a hint of $\Xi_b \to D^0 pK$ [LHCb-CONF-2011-036]





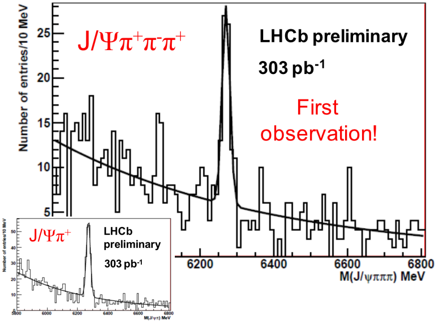


The orphan B_c

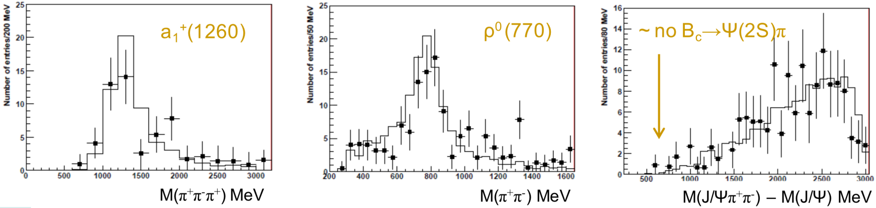
B_c has not been mentioned so far

- LHCb observes $B_c \to J/\psi\pi\pi\pi$ [LHCb-CONF-2011-040]

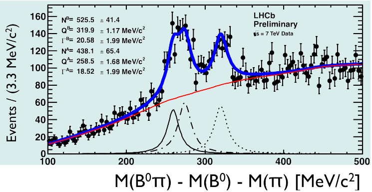
$$\frac{\mathcal{B}(B_c \to J/\psi\pi)}{\mathcal{B}(B_c \to J/\psi\pi\pi\pi)} = 3.0 \pm 0.6 \pm 0.4$$

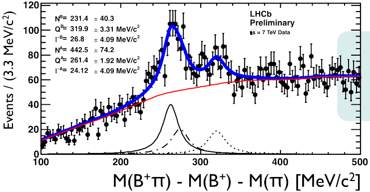


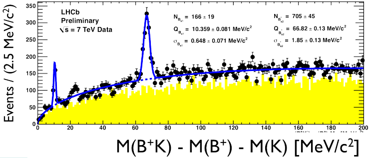
- Background subtracted mass distributions show a $\rho(770)$, $a_1(1260)$ but no $\psi(2S)$



Excited B states

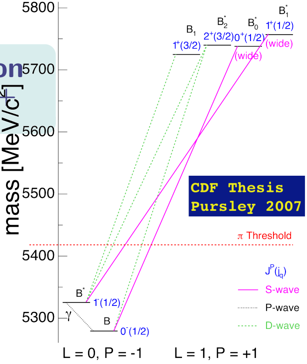






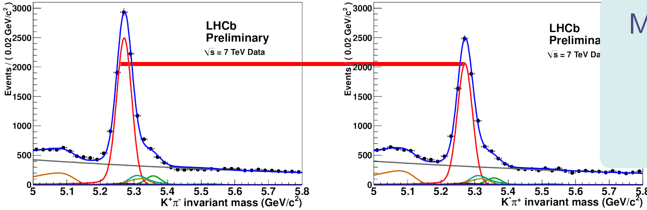
- Take exclusive $B_d \to J/\psi K^*$, $D\pi$, $D3\pi$, $B^+ \to J/\psi K$, $D\pi$, $D3\pi$ and combine with a K or a π
- $B^+\pi^-$ and B^+K^- modes have already been seen by CDF & D0.

First observation of $B^{+**} \to B^0\pi^+$



Direct CPV in charmless B Decays

See David Asner



Most precise single measurement!

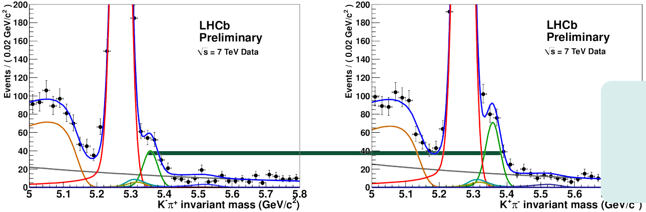
HFAG: -0.098 ± 0.013

➜ "$K\pi$ puzzle"

$$B_d \to K^+\pi^-: \ A_{\text{CP}} = -0.088 \pm 0.011 \pm 0.008$$

Production asymmetry: $(1.0 \pm 1.3)\%$, Interaction asymmetry $(-1.0 \pm 0.2)\%$

CP violation is that simple!



First evidence of CPV in B_s!

HFAG: 0.39 ± 0.017

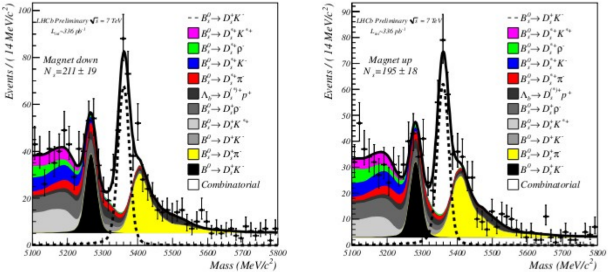
$$B_s \to K^-\pi^+: \ A_{\text{CP}} = 0.27 \pm 0.08 \pm 0.02$$

[LHCB-CONF-2011-042]

CKM-ANGLE γ

- $B \to hh$ measures γ via loop-induced transitions,
- While $B \to Dh$ and $B_s \to D_s h$ measure the "SM" value in tree-dominated decays
  - Similar to $B_d \to J/\psi K^0_S$ vs $B_d \to \phi K^0_S$ for $\sin 2\beta$
- Need more data for this programme. Now just observe and measure branching ratios: [LHCb-CONF-2011-057]

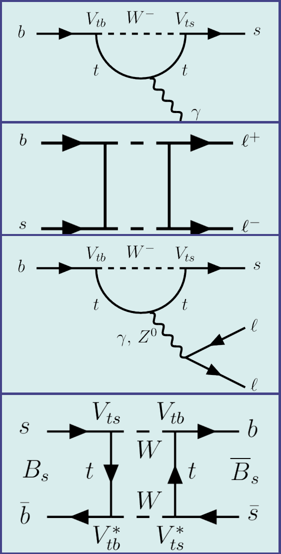
$$\mathcal{B}(B_s \to D_s K) = \left(1.97 \pm 0.18\,^{+0.19}_{-0.18}\,^{+0.11}_{-0.10}(f_s/f_d)\right) \cdot 10^{-4}$$



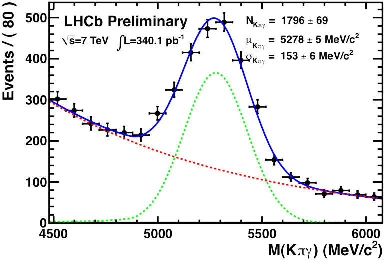
$b \to s$ TRANSITIONS

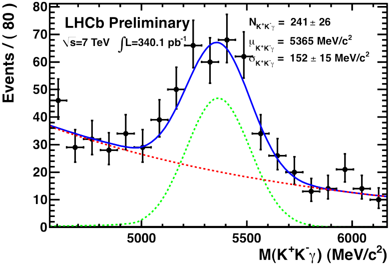
$b \to s$ transitions are loop-induced and thus suppressed in the SM. New Physics diagrams could compete.

1. $b \to s\gamma$
2. $B_s \to \mu\mu$
3. $b \to \ell\ell s$
4. CP violation in B_s mixing



$b \to s\gamma$





Ratio of $B \to K^*\gamma$ and $B_s \to \phi\gamma$

- ✗ Photons ➜ Broader signal peak than typical B decay
- ✗ More work on backgrounds ($B \to K\pi\pi^0 \ldots$)

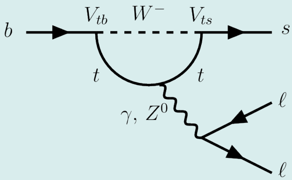
$$\frac{\mathcal{B}(B\to K^*\gamma)}{\mathcal{B}(B_s\to\phi\gamma)} = 1.52 \pm 0.15$$
$$\pm \quad 0.10 \pm 0.12\,(f_s/f_d)$$

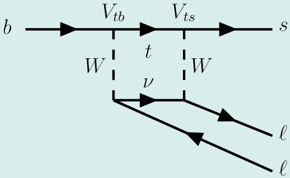
- Expect 1.0 ± 0.2 from SM ➜ 2σ
- ✔ Largest $B_s \to \phi\gamma$ signal!

[LHCb-CONF-2011-055]

➜ On the way to measuring CP asymmetries

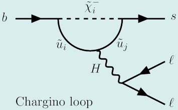
$b \to \ell\ell s$



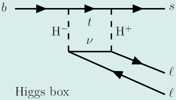


- Start with $b \to s\gamma$, pay a factor $\alpha_{\rm EM}$
  - ➜ Decay the γ into 2 leptons
  - Add an interfering box diagram
  - ➜ $b \to \ell\ell s$, very rare in the SM
    $\mathcal{B}(B \to \ell\ell K^*) = (3.3 \pm 1.0) \cdot 10^{-6}$
- Sensitive to Supersymmetry, Any 2HDM, Fourth generation, Extra dimensions, Axions ...

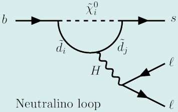
✔ Ideal place to look for new physics



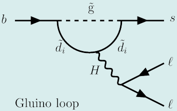
Chargino loop



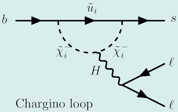
Higgs box



Neutralino loop



Gluino loop



Chargino loop

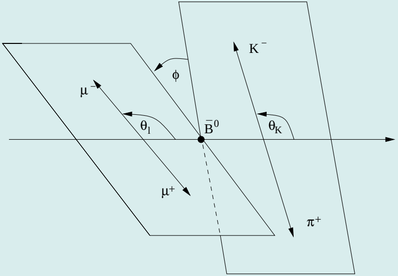
ANGULAR DISTRIBUTIONS & A_{FB}

A lot of information in the full θ_ℓ, θ_K and ϕ distributions

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\theta_l} = \Gamma'\left(\frac{3}{4}F_L\sin^2\theta_l + A_{\mathrm{FB}}\cos\theta_l + \frac{3}{8}(1-F_L)(1+\cos^2\theta_l)\right)$$

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\phi} = \frac{\Gamma'}{2\pi}\left(\frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{\mathrm{Im}}\sin 2\phi + 1\right)$$

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\theta_K} = \frac{3\Gamma'}{4}\sin\theta_K\left(2F_L\cos^2\theta_K + (1-F_L)\sin^2\theta_K\right)$$



➜ Many observables depending on $q^2 = m_{\mu\mu}^2 c^4$

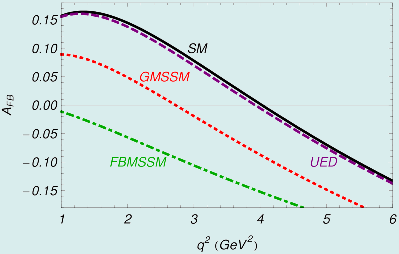
rüger & Matias]
[Egede, et al.] [Ali, et al.]

Angular Distributions & A_{FB}

A lot of information in the full θ_ℓ, θ_K and ϕ distributions

$$\frac{\mathrm{d}\Gamma'}{\mathrm{d}\theta_l} = \Gamma'\left(\frac{3}{4}F_L\sin^2\theta_l + A_{\mathrm{FB}}\cos\theta_l + \frac{3}{8}(1-F_L)(1+\cos^2\theta_l)\right)$$

$$A_{\mathrm{FB}} = \frac{\left(\int_0^1 - \int_{-1}^0\right)\mathrm{d}\cos\theta_l \frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_l}}{\int_{-1}^1 \mathrm{d}\cos\theta_l \frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_l}}$$



→ **Today: Forward-backward asymmetry A_{FB}**

rüger & Matias]
[Egede, et al.] [Ali, et al.]

$A_{\rm FB}$ Measurements Summary

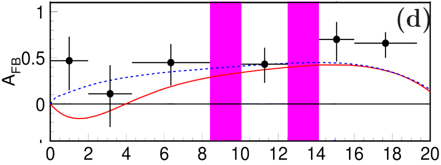
Belle: 230 $B \to \ell\ell K^*$ events in $657 \cdot 10^6$ $B\overline{B}$ [PRL103:171801,2009]

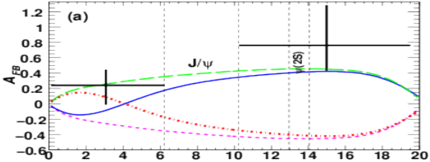
BaBar: 60 $B \to \ell\ell K^*$ events in $384 \cdot 10^6$ $B\overline{B}$ [PRD79:031102,2009]

CDF: 100 $B \to \mu\mu K^*$ events in $4.4\ \mathrm{fb}^{-1}$ [CDF public note]

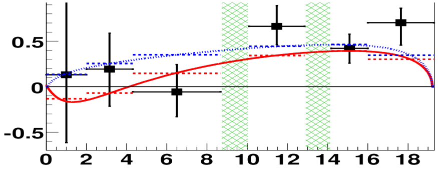
FB asymmetry: All seem to favour positive values in first bins. Not conclusive yet...

➜ Need much more statistics



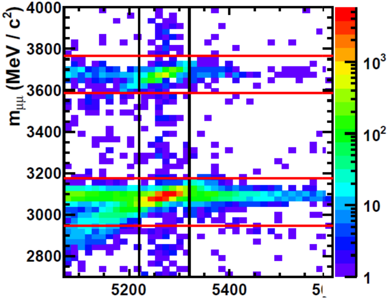


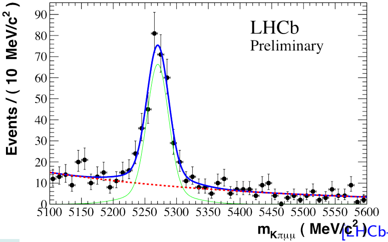
LHCb presents a result with 300 events with 309 pb^{-1}: Largest sample in the world



[LHCb-CONF-2011-038]

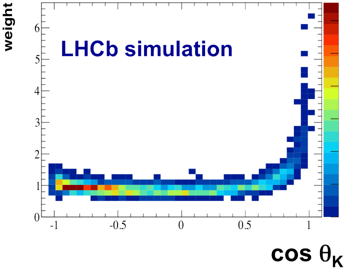
$B \to \mu\mu K^*$ at LHCb



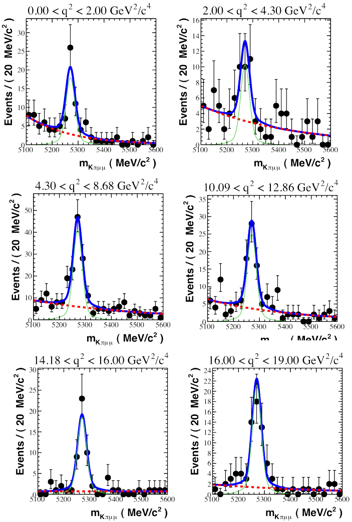


[LHCb-CONF-2011-038]

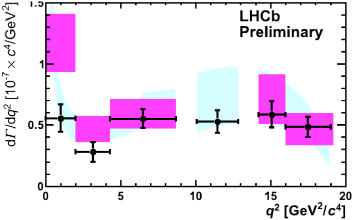
- Select $B^0 \to K^* \mu^+ \mu^-$ using boosted decision tree
  - Cut out J/ψ and $\psi(2S)$ (used as control of angular fits)
- Weight events according to $\eta^{-1}(\theta_\ell, \phi, \theta_K, q^2)$



$B \to \mu\mu K^*$ at LHCb



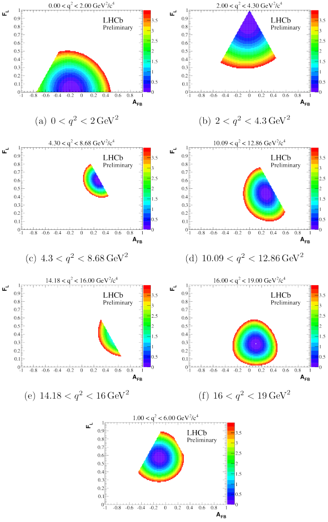
- Select $B^0 \to K^* \mu^+ \mu^-$ using boosted decision tree
  - Cut out J/ψ and $\psi(2S)$ (used as control of angular fits)
- Weight events according to $\eta^{-1}(\theta_\ell, \phi, \theta_K, q^2)$
- Bin in q^2 and extract $\mathrm{d}\Gamma/\mathrm{d}q^2$



[LHCb-CONF-2011-038]

SM: Bobeth et al., [arXiv:1105.0376]

$B \rightarrow \mu\mu K^*$ at LHCb



(a) $0 < q^2 < 2\,\mathrm{GeV}^2$ (b) $2 < q^2 < 4.3\,\mathrm{GeV}^2$

(c) $4.3 < q^2 < 8.68\,\mathrm{GeV}^2$ (d) $10.09 < q^2 < 12.86\,\mathrm{GeV}^2$

(e) $14.18 < q^2 < 16\,\mathrm{GeV}^2$ (f) $16 < q^2 < 19\,\mathrm{GeV}^2$

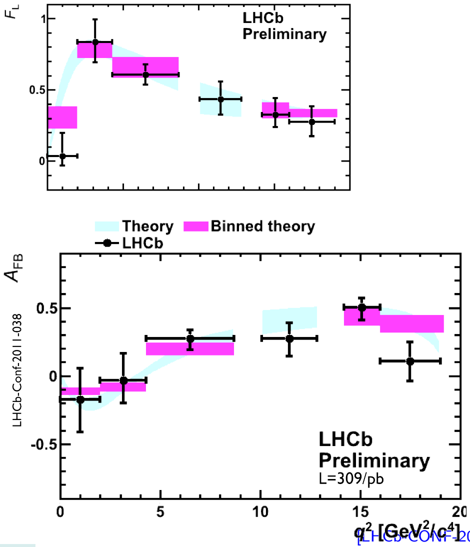
(g) $1 < q^2 < 6\,\mathrm{GeV}^2$

- Select $B^0 \rightarrow K^*\mu^+\mu^-$ using boosted decision tree
  - Cut out J/ψ and $\psi(2S)$ (used as control of angular fits)
- Weight events according to $\eta^{-1}(\theta_\ell, \phi, \theta_K, q^2)$
- Bin in q^2 and extract $\mathrm{d}\Gamma/\mathrm{d}q^2$
- Fit for θ_K and θ_ℓ

[LHCb-CONF-2011-038]

SM: Bobeth et al., [arXiv:1105.0376]

$B \to \mu\mu K^*$ at LHCb

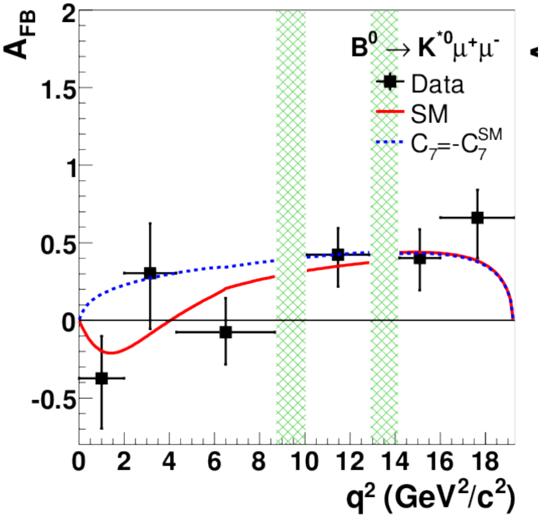


- Select $B^0 \to K^* \mu^+ \mu^-$ using boosted decision tree
  - Cut out J/ψ and $\psi(2S)$ (used as control of angular fits)
- Weight events according to $\eta^{-1}(\theta_\ell, \phi, \theta_K, q^2)$
- Bin in q^2 and extract $\mathrm{d}\Gamma/\mathrm{d}q^2$
- Fit for θ_K and θ_ℓ
  - ➜ Good agreement with SM
  - Will add more observables, like A_T^2, sensitive to right handed currents

[LHCb-CONF-2011-038]

SM: Bobeth et al., [arXiv:1105.0376]

New CDF Result

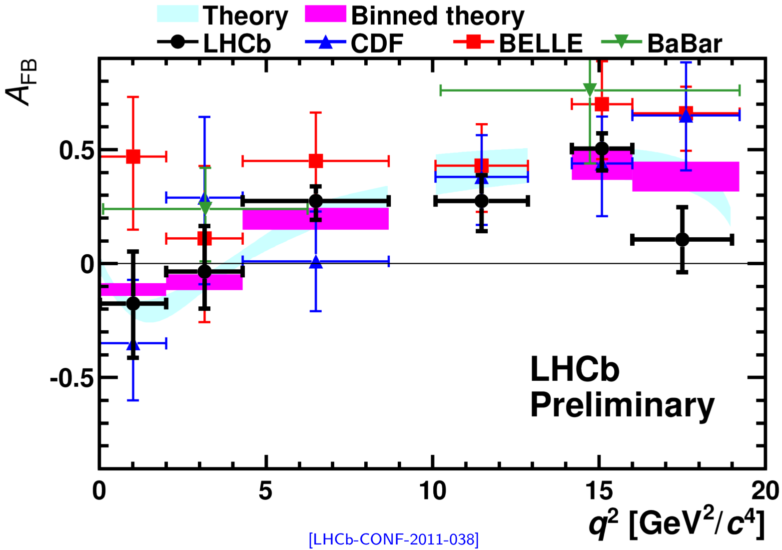


- CDF has released an update to 6.8 fb^{-1} → 165 candidates

  [arXiv:1108.0695]

- They now also see a negative A_{FB} in the first bin

Comparison of all experiments



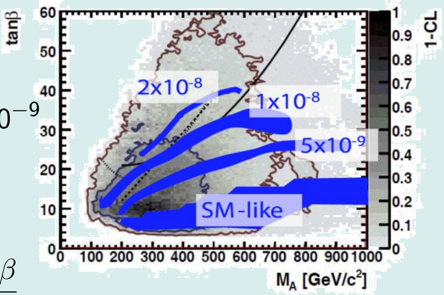
[LHCb-CONF-2011-038]

$B_s \to \mu\mu$

- Very rare decay, well described in the SM

$$\mathcal{B}(B_s \to \mu\mu)_{\text{SM}} = (3.2 \pm 0.2) \cdot 10^{-9}$$

[Buras]



- Very sensitive to NP, e.g. MSSM:

$$\mathcal{B}(B_s \to \mu\mu)_{\text{MSSM}} \propto \frac{m_b^2 m_\ell^2 \tan^6\beta}{m_A^4}$$

Many previous measurements

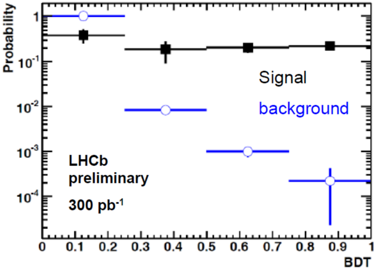
D0 ($6.1\ \text{fb}^{-1}$): $\mathcal{B} < 5.1 \cdot 10^{-8}$ (95%) [Phys. Lett. B 693, 539 (2010)]

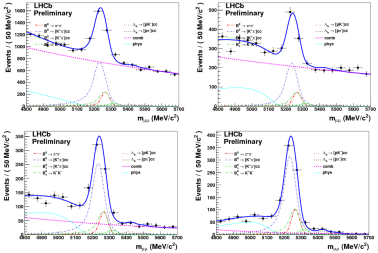
LHCb ($37\ \text{pb}^{-1}$): $\mathcal{B} < 5.6 \cdot 10^{-8}$ (95%) [Phys. Lett. B 699, 330 (2011)]

CDF ($7\ \text{fb}^{-1}$): $\mathcal{B} = (1.8\,^{+1.1}_{-0.9}) \cdot 10^{-8}$ Hint! [arXiv:1107.2304]

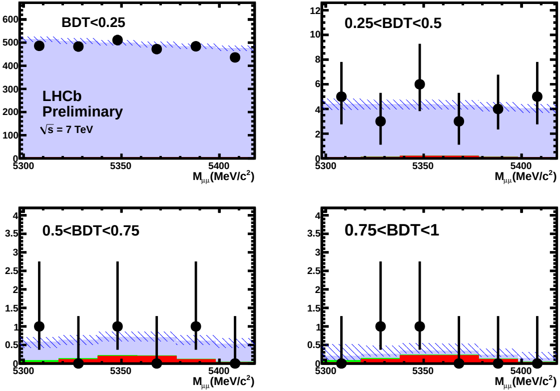
$B_s \to \mu\mu$ Strategy (300 pb^{-1})

1. Select $B \to \mu\mu$ using a boosted decision tree (BDT) tuned on MC but calibrated on real data $B \to hh$ and sidebands
2. Mass resolution calibrated on $b \to hh$ and dimuon resonances
3. Look in 4×6 bins of BDT×Mass
4. Normalise to $B_s \to J/\psi\phi$, $B_d \to J/\psi K^*$, $B_s \to K\pi$





$B_s \to \mu\mu$ Signal window (300 pb^{-1})



- Data

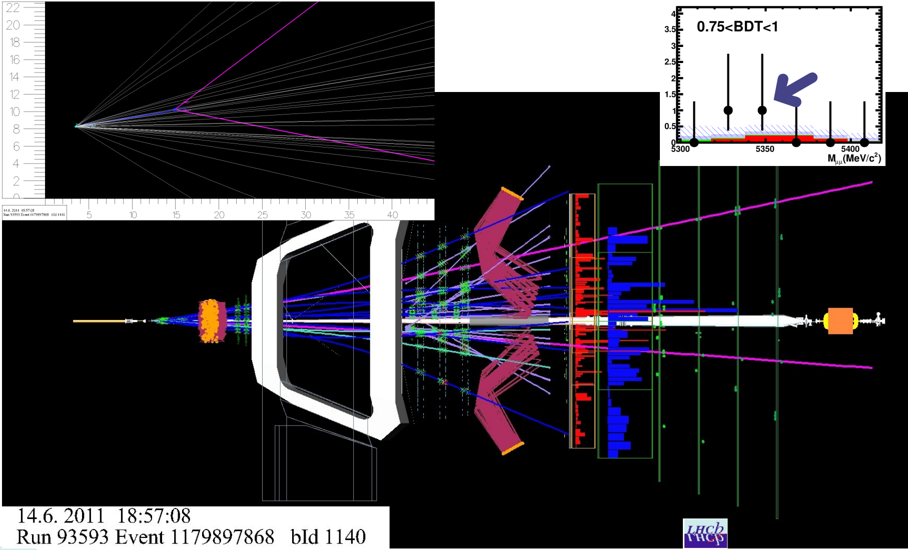
SM signal expectation

$B \to \pi\pi$ expectation

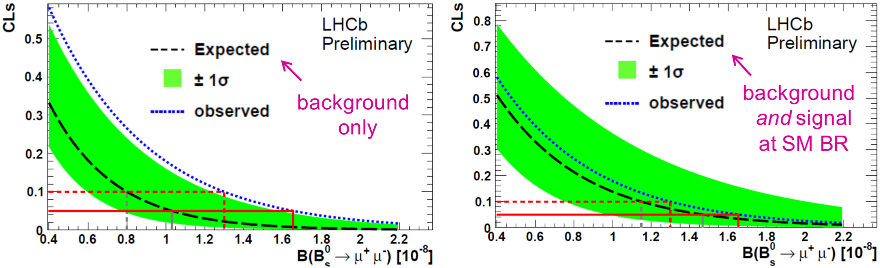
Combinatorial expectation

BDT Bin	1	2	3	4
Exp. Comb. Bkg.	2969 ± 69	25 ± 3	3.0 ± 0.9	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

$B_s \to \mu\mu$ Best Candidate



$B \to \mu\mu$ LHCb LIMITS (300+37 pb^{-1})

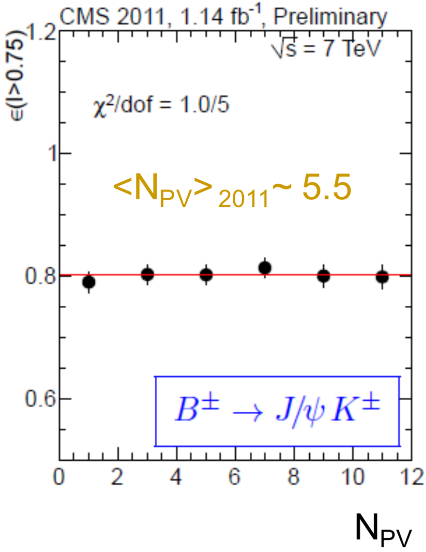


	$B_s \to \mu\mu$	$B_d \to \mu\mu$
Expected limit assuming bkg only (95%)	$1.0 \cdot 10^{-8}$	$3.1 \cdot 10^{-9}$
Expected limit assuming bkg+SM (95%)	$1.5 \cdot 10^{-8}$	
Observed limit (95%)	$1.6 \cdot 10^{-8}$	$\mathbf{5.1 \cdot 10^{-9}}$
p-value of background only hypothesis	14%	79%
Observed limit, 2010+2011 (95%)	$\mathbf{1.5 \cdot 10^{-8}}$	

[LHCB-CONF-2011-037-001]

$B_s \to \mu\mu$ at CMS ($1.1\ \mathrm{fb}^{-1}$)

- Cut-based selection optimised on MC and sidebands
- Divided in Barrel (two μ with $|\eta| < 1.4$) and Endcap (one μ with $|\eta| > 1.4$)
- Efficiency very stable wrt to multiplicity ➜ good news for high lumi running
- Normalisation to $B_s \to J/\psi\phi$, $B_u \to J/\psi K$

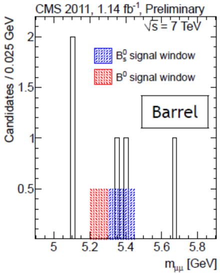


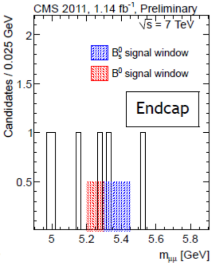
$B_s \to \mu\mu$ at CMS ($1.1\ \mathrm{fb}^{-1}$)

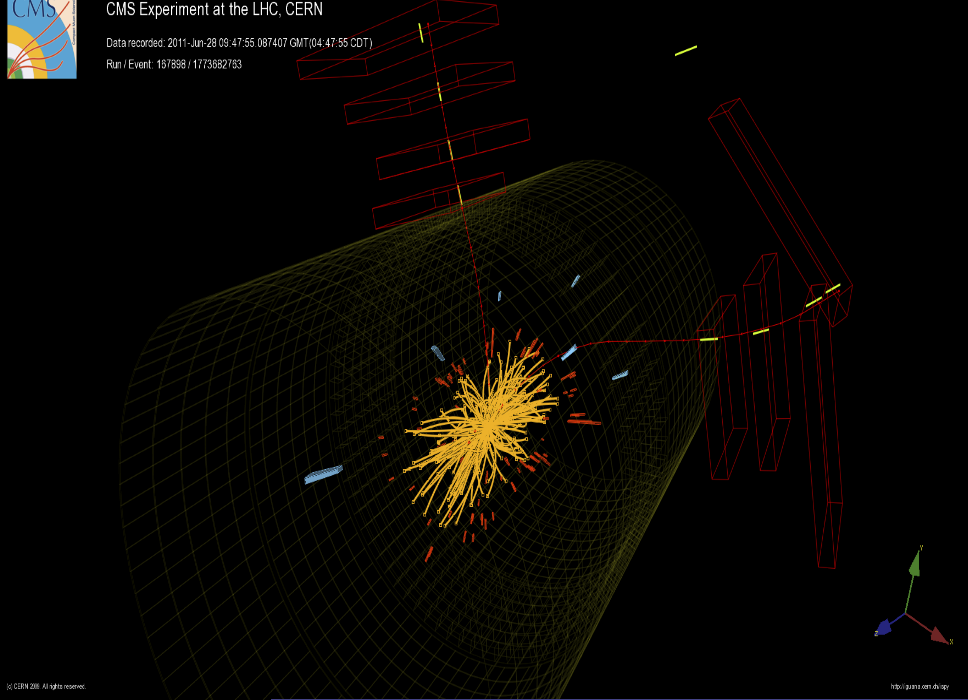
	Barrel	Endcap
Expected signal	0.80 ± 0.16	0.36 ± 0.07
Expected Bkg	0.60 ± 0.35	0.80 ± 0.40
Expected $B \to hh$	0.07 ± 0.02	0.04 ± 0.02
Observed	2	1

Expected limit at 95% assuming SM	$1.8 \cdot 10^{-8}$
Observed limit	$\mathbf{1.9 \cdot 10^{-8}}$
p-value of background only hypothesis	11%

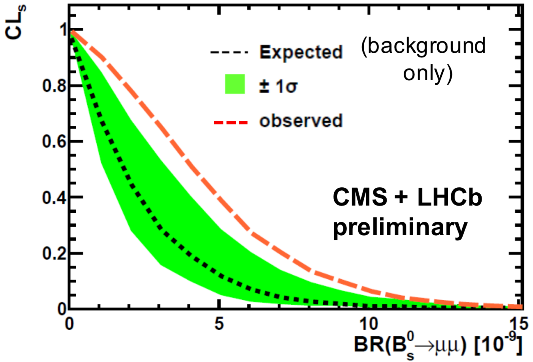
[1107.5834, submitted to PRL]






CMS Experiment at the LHC, CERN
Data recorded: 2011-Jun-28 09:47:55.087407 GMT(04:47:55 CDT)
Run / Event: 167898 / 1773682763
(c) CERN 2009. All rights reserved.
http://iguana.cern.ch/ispy

$B_s \to \mu\mu$ LHC combination

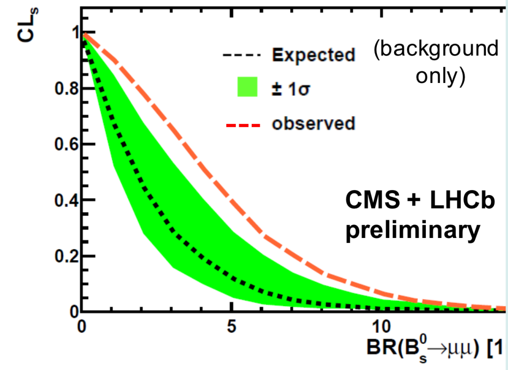


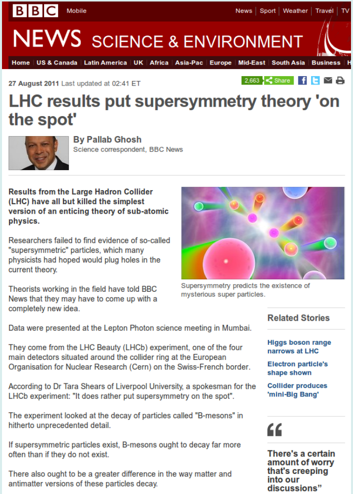
- Combine using LHCb's framework, with 24 LHCb plus 2 CMS bins.
- Use f_d/f_s from LHCb.

	LHCb	CMS
Expected Limit, SM+Bkg (95%)	$1.5 \cdot 10^{-8}$	$1.8 \cdot 10^{-8}$
Observed limit, 2010+2011 (95%)	$1.5 \cdot 10^{-8}$	$1.9 \cdot 10^{-8}$
Observed LHCb+CMS limit (95%)	$\mathbf{1.1 \cdot 10^{-8}}$	

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

$B_s \to \mu\mu$ LHC combination





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27 August 2011 Last updated at 02:41 ET

2,663 Share

LHC results put supersymmetry theory 'on the spot'

By Pallab Ghosh
Science correspondent, BBC News

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had hoped would plug holes in the current theory.

Theorists working in the field have told BBC News that they may have to come up with a completely new idea.

Supersymmetry predicts the existence of mysterious super particles.

Data were presented at the Lepton Photon science meeting in Mumbai.

They come from the LHC Beauty (LHCb) experiment, one of the four main detectors situated around the collider ring at the European Organisation for Nuclear Research (Cern) on the Swiss-French border.

According to Dr Tara Shears of Liverpool University, a spokesman for the LHCb experiment: "It does rather put supersymmetry on the spot".

The experiment looked at the decay of particles called "B-mesons" in hitherto unprecedented detail.

If supersymmetric particles exist, B-mesons ought to decay far more often than if they do not exist.

There also ought to be a greater difference in the way matter and antimatter versions of these particles decay.

Related Stories

Higgs boson range narrows at LHC

Electron particle's shape shown

Collider produces 'mini-Big Bang'

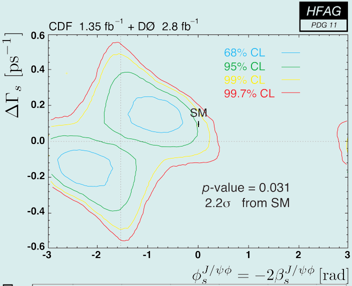
"There's a certain amount of worry that's creeping into our discussions"

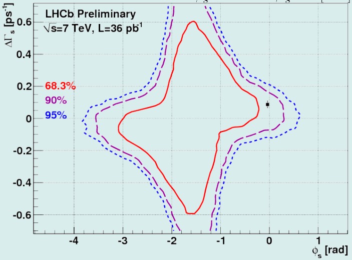
The air is getting thin for Susy

Assuming the SM we could get 3σ evidence with 2011 data. [arXiv:1108.3018]

ϕ_s IN $B_s \to J/\psi\phi$ STATUS

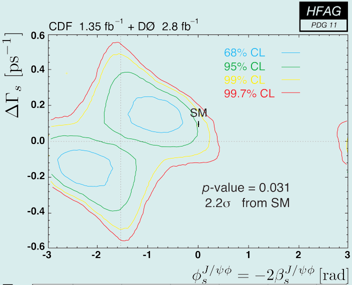
See Rob Harr

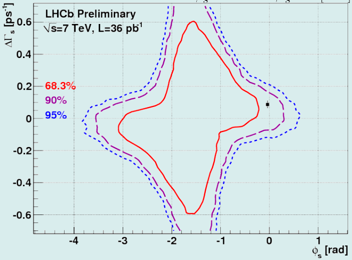




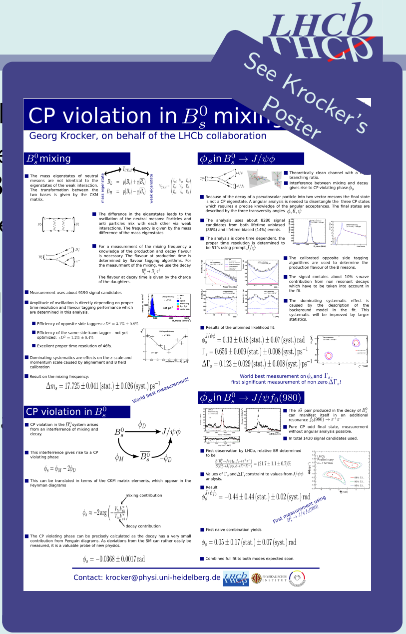
- ϕ_s is the phase in the B_s mixing
- SM prediction $= 0.0363 \pm 0.0017$ rad [CKMFitter]
  - Deviations due to NP could large
- HFAG, UTFit, CKMFitter fits hint towards an additional phase [HFAG]
- LHCb has measured it with 2010 data : 37 pb^{-1}, 757 ± 28 signal candidates [LHCb-CONF-2011-006]
- Now updating to 10 times more

ϕ_s in $B_s \to J/\psi\phi$ Status



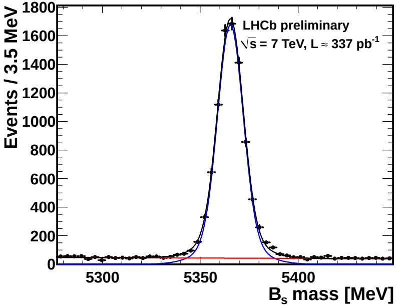


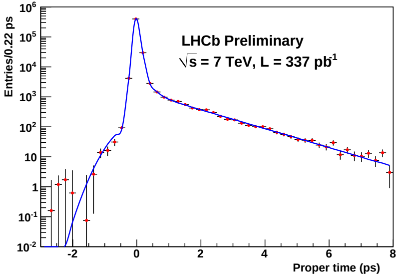
- ϕ_s is t
- SM pre
  $= 0.03$
  - De
- HFAG,
  toward
- LHCb
  data :
  candid
- Now u



$B_s \to J/\psi\phi$

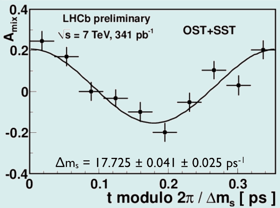
1. Time dependent analysis
   Time resolution measured using prompt J/ψ background: $\sigma_\tau = 50$ fs





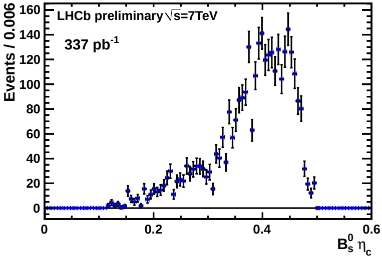
$B_s \to J/\psi\phi$

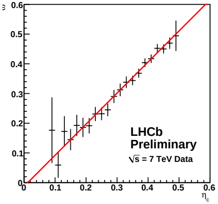
1. Time dependent analysis
2. Need to tag initial flavour of the B_s
   - Per event mistag calibrated on $B^+ \to J/\psi K$ and $B_d \to D^*\mu\nu_\mu$
   - Dilution $D_{\text{tag}} = 0.277 \pm 0.011 \pm 0.025$
   - Tagging power $\epsilon D^2 = (2.08 \pm 0.41)\%$

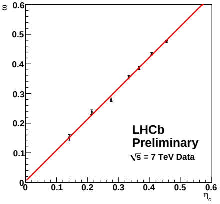


Mixing seen in $B_s \to D_s\pi$

See Bob Harr's talk

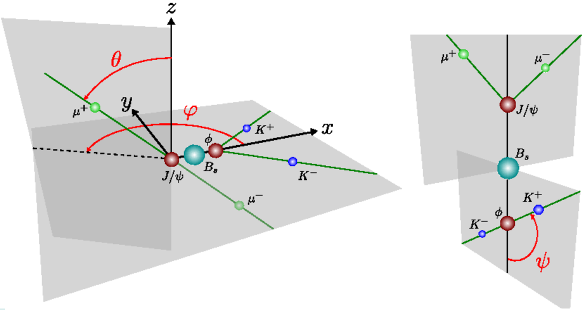


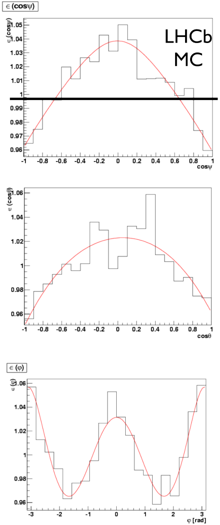




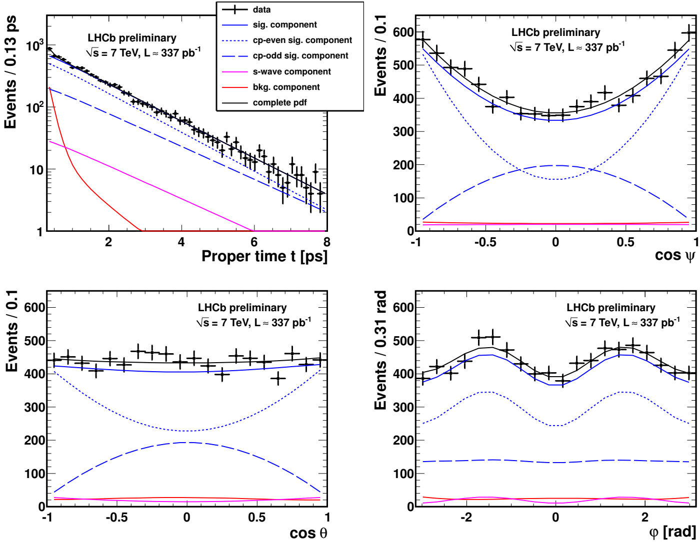
$B_s \to J/\psi\phi$

1. Time dependent analysis
2. Need to tag initial flavour of the B_s
3. P→VV decay: needs an angular analysis to resolve CP-even and CP-odd components
   - Angular acceptance determined from MC
   - Maximum deviation from uniform: 5%



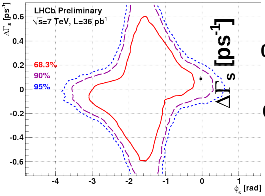


$B_s \to J/\psi\phi$ Fit projections

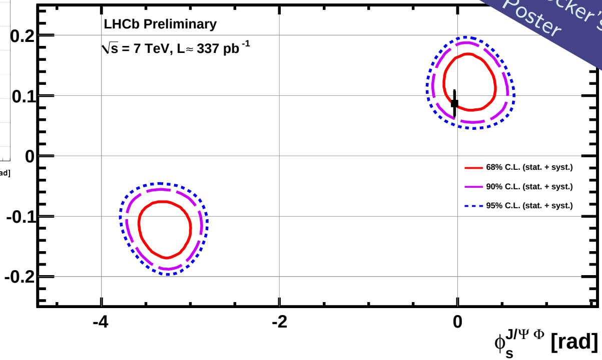


ϕ_s in $B_s \to J/\psi\phi$ Result

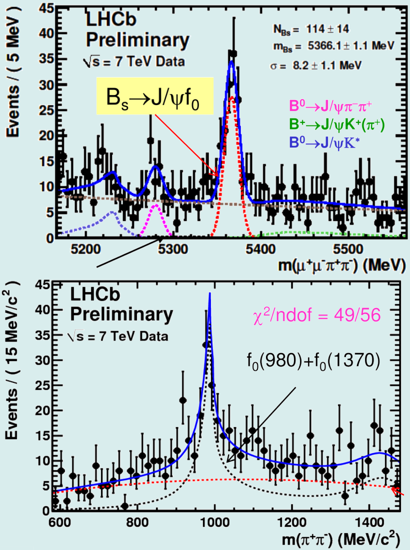
See Krocker's Poster



First evidence (4σ) of $\Delta\Gamma_s > 0$!



$$\phi_s^{J/\psi\phi} = 0.13 \pm 0.18\ \text{(stat)} \pm 0.07\ \text{(sys) rad}$$
$$\Gamma_s = 0.656 \pm 0.009\ \text{(stat)} \pm 0.008\ \text{(sys)}\ \text{ps}^{-1}$$
$$\Delta\Gamma_s = 0.123 \pm 0.029\ \text{(stat)} \pm 0.008\ \text{(sys)}\ \text{ps}^{-1}$$



✔ First observation of $B_s \to J/\psi f_0(980)$ ($f_0(980) \to \pi\pi$)

[Phys. Letters B 698 (2011) 115]

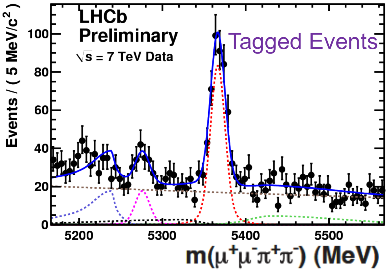
- That was in February this year
  - Almost immediately confirmed by Belle

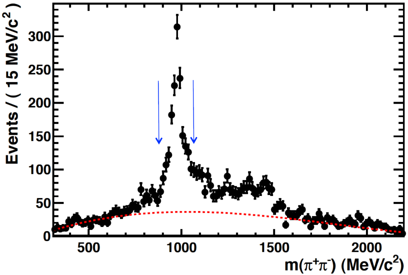
    [Phys.Rev.Lett.106:121802,2011]

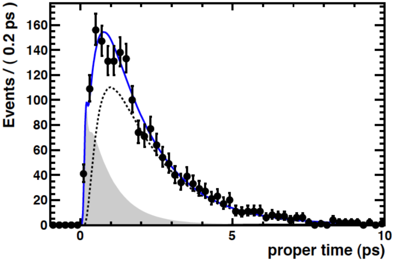
    and CDF

    [arXiv:http://arxiv.org/abs/1106.3682]

ϕ_s IN $B_s \to J/\psi f_0(980)$ $(330\ \mathrm{pb}^{-1})$

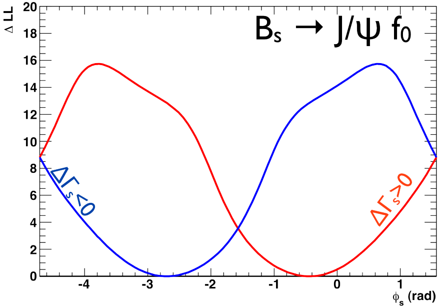


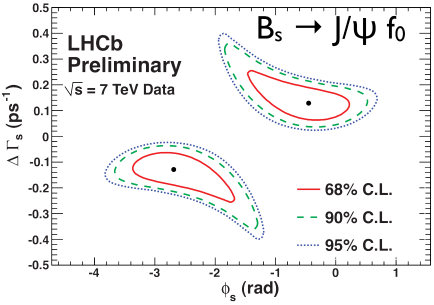




- Now we use it to extract ϕ_s
- ✔ The $f_0(980)$ looks pure scalar: no angular analysis needed.

ϕ_s IN $B_s \to J/\psi f_0(980)$

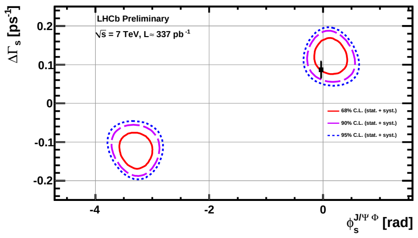


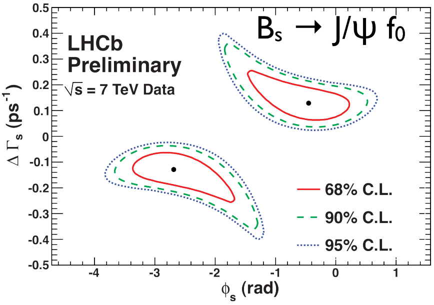


$$\phi_s^{J/\psi f_0(980)} = -0.44 \pm 0.44 \pm 0.02 \text{ rad}$$

SM fit: -0.0363 ± 0.0017 rad

ϕ_s IN $B_s \to J/\psi f_0(980)$ AND ϕ





Combining with $J/\psi\phi$ result:

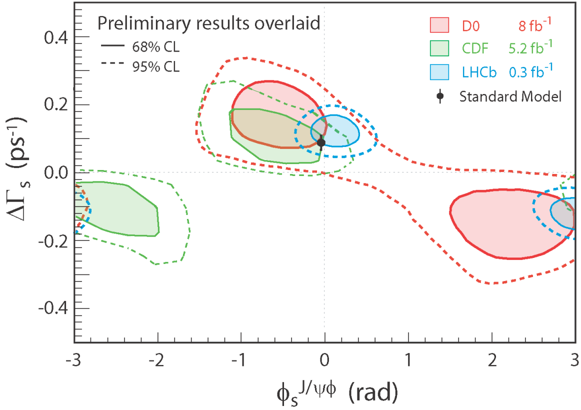
$$\phi_s^{J/\psi f_0(980)} = -0.44 \pm 0.44 \pm 0.02 \text{ rad}$$

$$\phi_s^{J/\psi\phi} = +0.13 \pm 0.18 \pm 0.07 \text{ rad}$$

$$\phi_s^{\text{Comb}} = +0.03 \pm 0.16 \pm 0.07 \text{ rad (LHCb)}$$

SM fit: -0.0363 ± 0.0017 rad

ϕ_s IN $B_s \to J/\psi f_0(980)$ AND ϕ



LHCb the first to show point-estimates.

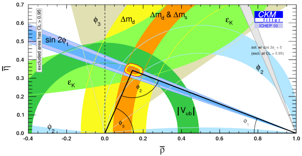
No need for $\Delta\Gamma_s/\phi_s$ plots any more.

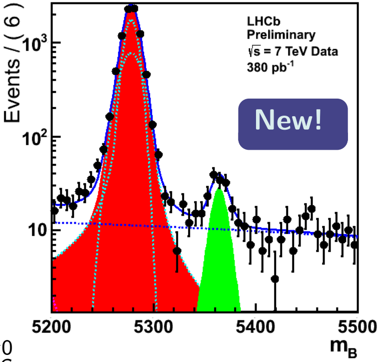
$$\phi_s^{\text{Comb}} = +0.03 \pm 0.16 \pm 0.07 \text{ rad (LHCb)}$$

SM fit: -0.0363 ± 0.0017 rad

Controlling Penguins

With LHCb's experimental precision, penguin contributions to e.g. $B_d \to J/\psi K_S^0$ will have to me taken into account





[LHCb-CONF-2011-048]

Is that the tension on $\sin 2\beta$?

➜ Study U-spin partners as $B_s \to J/\psi K_S^0$

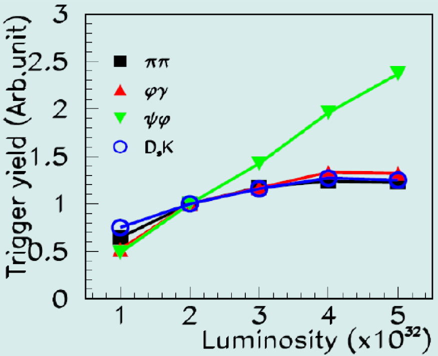
De Bruyn, PK, Fleischer [Eur.Phys.J.C70:1025 (2010)], [arXiv:1012.0840]

$$\frac{\mathcal{B}(B_s \to J/\psi K_S^0)}{\mathcal{B}(B_d \to J/\psi K_S^0)} = 0.0378 \pm 0.0058\,(\text{stat}) \pm 0.0020\,(\text{syst}) \pm 0.0030\,\left(\frac{f_s}{f_d}\right)$$

CDF: $0.041 \pm 0.007 \pm 0.004 \pm 0.005$ [Note 10240]

LHCb Upgrade plans

- Expect that integrated luminosity increases linearly with time. After 6 fb^{-1}, would take $\sim$3 years to double statistics
  - Need an order of magnitude increase in luminosity ➜ $\mathcal{O}(10^{33})$
  - ✔ Most of the detector can cope, efficiencies don't degrade
- ✗ L0 saturates for hadronic channels
  - p_T is not a discriminating variable anymore
  - ➜ Cut on impact parameter
- ➜ Read all out at 40 MHz
  - Most of the electronics to be replaced



[CERN-LHCC-2011-001]

Conclusion

- The LHC is the new b factory
- Big industry of cross section measurements at $\sqrt{s} = 7$ TeV
- The charm cross section is large ➜ good prospects for D physics
- Exploring b $\rightarrow$ s transitions
  - $B_s \rightarrow \mu\mu$, $B \rightarrow \mu\mu K^*$, ϕ_s
  - The LHC does not confirm the hints seen by the Tevatron or B factories
  - But all measurements are statistically limited
- More to come in 2012, including CKM angles. . .

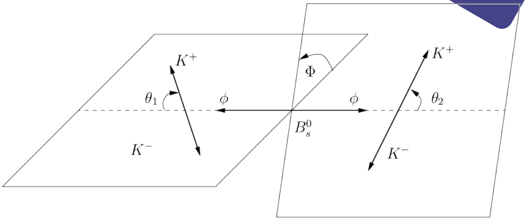
Backup

$B_s \to \phi\phi$ TRIPLE PRODUCT

See Rob Harr

$B_s \to \phi\phi$ is similar to $B_s \to J/\psi\phi$, but only penguin-induced.

Triple product tests for CP violation without need of flavour tagging [arXiv:1107.1232], [Phys.Lett. B701 (2011) 357-362]



$$U = \sin\phi\cos\phi$$
$$V = +\sin\phi, \text{ if } \cos\theta_1\cos\theta_2 > 0$$
$$V = -\sin\phi, \text{ otherwise}$$

$B_s \to \phi\phi$ TRIPLE PRODUCT

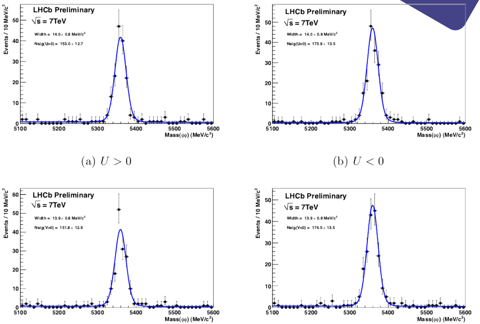
See Rob Harr

$B_s \to \phi\phi$ is similar to $B_s \to J/\psi\phi$, but only penguin-induced.

Triple product tests for CP violation without need of flavour tagging [arXiv:1107.1232], [Phys.Lett. B701 (2011) 357-362]

$$
\begin{aligned}
U &= \sin\phi\cos\phi \\
V &= +\sin\phi,\ \text{if} \cos\theta_1\cos\theta_2 > 0 \\
V &= -\sin\phi,\ \text{otherwise}
\end{aligned}
$$

Very clean signal: 320 events in 340 pb^{-1}



(a) $U > 0$ (b) $U < 0$ (c) $V > 0$ (d) $V < 0$

$$
\begin{aligned}
A_U &= -0.064 \pm 0.057 \pm 0.014 \\
A_V &= -0.070 \pm 0.057 \pm 0.014
\end{aligned}
$$

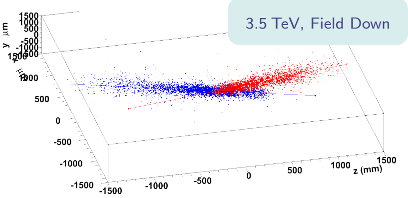
[CONF-2011-052]

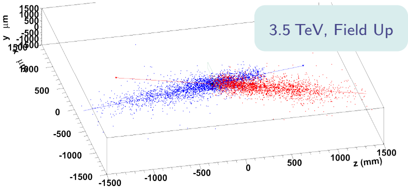
Luminosity

Dipole magnet ➜ crossing angle

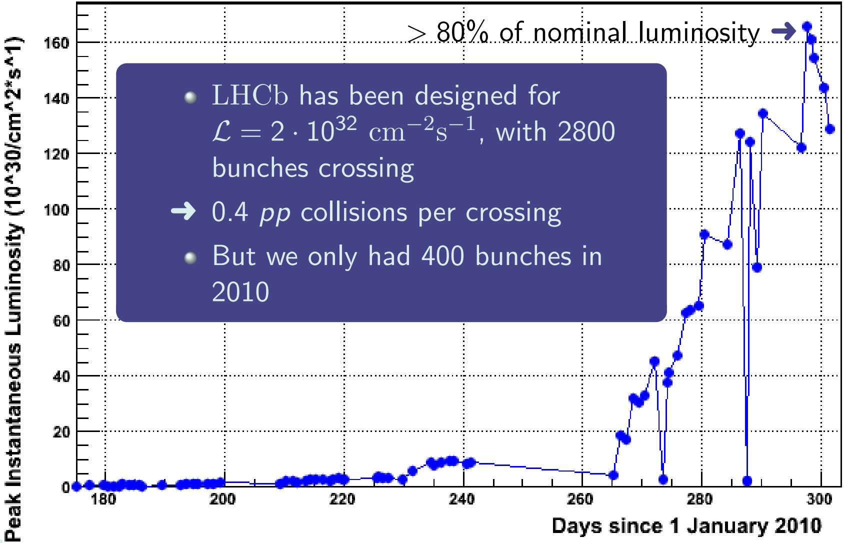
- added or subtracted from external angle
- Beam-gas events allow to measure beam shapes

➜ Precise measurement of LHC luminosity





Instantaneous Luminosity at 3.5 TeV

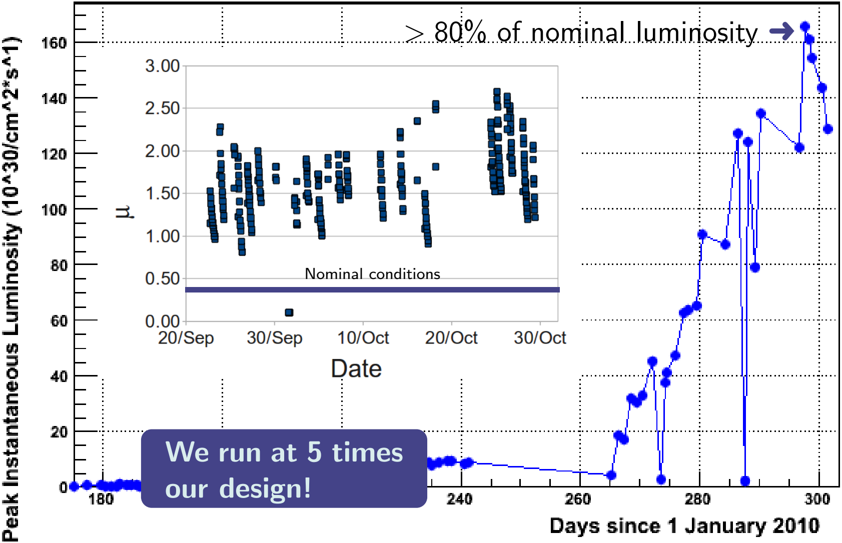


- LHCb has been designed for $\mathcal{L} = 2 \cdot 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, with 2800 bunches crossing

➜ 0.4 *pp* collisions per crossing

- But we only had 400 bunches in 2010

Instantaneous Luminosity at 3.5 TeV



We run at 5 times our design!