Heavy Flavours and the SM@LHC

(discussion provocation)

Paul Harrison
U. Warwick

Durham, 14th April 2011

- Reviewed two areas of the SM in HF sessions: Production and Decays.
  - Production (strong int.)
    - Exclusive Central production of onia at LHC(b) (McNulty)
    - Production of B and D at LHC (Bouhova-Thacker)
    - Production of onia generally at LHC (Coccaro)
  - Decay (weak int. - mostly)
    - Theoretical Overview and Challenges (Feldmann)
    - Rare B decays @LHC (Elsasser)
    - B oscillations and CP violation @LHC (Brambach)

Step Back - What do we Mean by the SM?

- 3 gauge theories and an experimentally-determined particle content.
- SM has 25 parameters:

  3 gauge couplings, Higgs mass and vev, 6 quark masses, 4 quark mixings, 6 lepton masses, 4 lepton mixings (+ anything else needed if neutrinos are majorana particles).
- In principle, everything should be explicable in terms of these? (yeah right!)
- There are subsidiary “parameters” which are not "fundamental" but nevertheless are needed in order to make predictions (eg. MC tuning!).

Activities of particle physicists divide in broadly into 3 types:

- 1). Determining the SM (parameters)
- 2). Testing the SM (looking for disagreements between the SM and its associated parameters and data).
- 3). Speculating beyond the SM based on recognised deficiencies (theorists)

HF@LHC in that context

- Since 1) has largely been accomplished (apart from measuring the Higgs mass), plans @LHC are largely concerned with 2).

- Efforts _so far_ @LHC, however, have largely been preparatory, being more concerned with proving that the detectors are working, and in determining how much Monte Carlo’s need tuning.

How have this Week's Results Contributed to Program?

Central Exclusive Onia (McNulty) Comparison Exp. to Theory

$$\sigma_{J\psi\to\mu^+\mu^-}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5) = 474 \pm 12 \pm 45 \pm 92\,\mathrm{pb}$$

$$\sigma_{\psi'\to\mu^+\mu^-}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5) = 14.4 \pm 2.2 \pm 1.3 \pm 2.8\,\mathrm{pb}$$

$$\sigma_{\chi_0\to J\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 9.3 \pm 2.2 \pm 3.5 \pm 1.8\,\mathrm{pb}$$

$$\sigma_{\chi_1\to J\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 16.4 \pm 5.3 \pm 5.8 \pm 3.2\,\mathrm{pb}$$

$$\sigma_{\chi_2\to J\psi\gamma\to\mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 28.0 \pm 5.4 \pm 9.7 \pm 5.4\,\mathrm{pb}$$

$$\sigma_{pp\to p\mu^+\mu^-p}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5; m_{\mu+\mu-} > 2.5GeV) = 67 \pm 10 \pm 5 \pm 15\,\mathrm{pb}$$

Jpsi: 292pb (Starlight) 330pb (SuperChic) 330pb (Motyka & Watt) 710pb (Schaefer & Szczurek) (big uncertainty!)

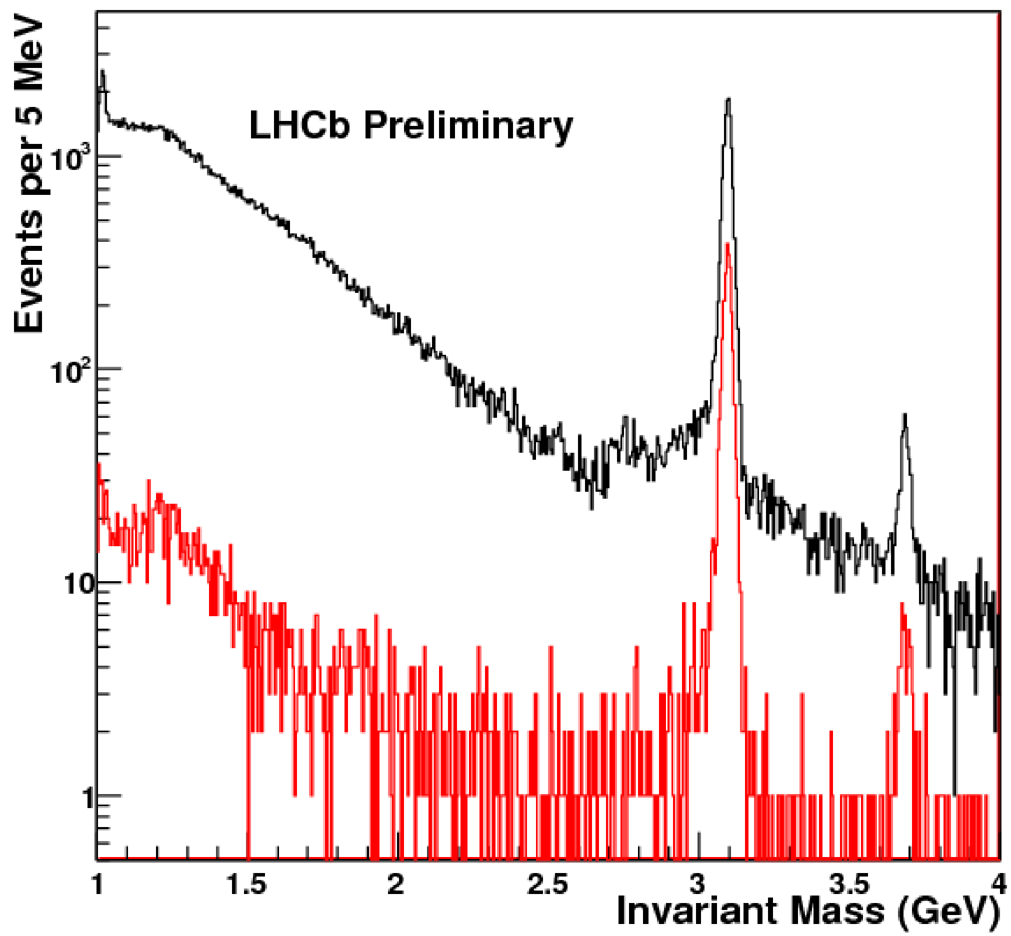
Psip: 6pb (Starlight) 17pb (Schaefer & Szczurek)

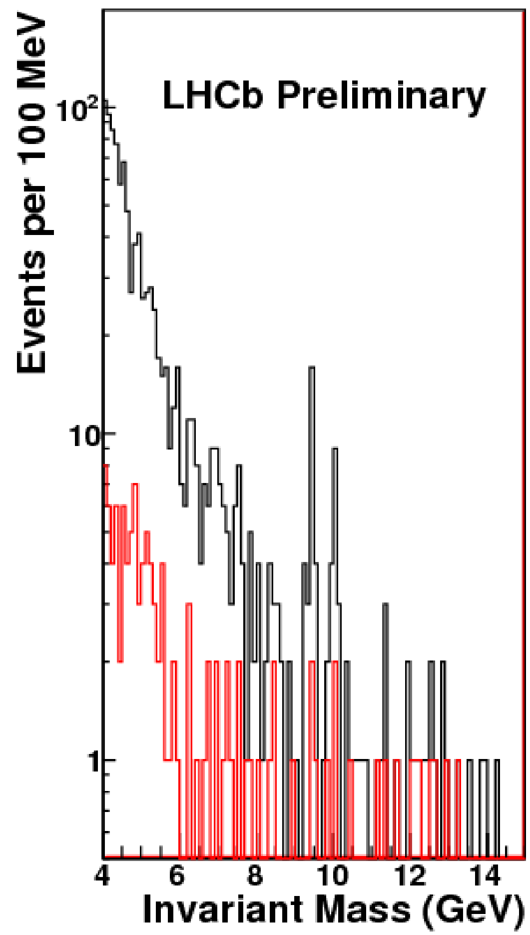
Ratio: **We measure 0.20+-0.03 Systematics Cancel**. 0.16 (Starlight) ~0.2 (Schaefer & Szczurek). HERA: 0.166+-0.012 CDF: 0.14+-.05. (Lower √s)

Chic: 14, 10, 3 pb (SuperChic)

pμμp: 42 (LPAIR) (offers potential for Luminosity measurement)

Evidence for Pomeron?! (McNulty)

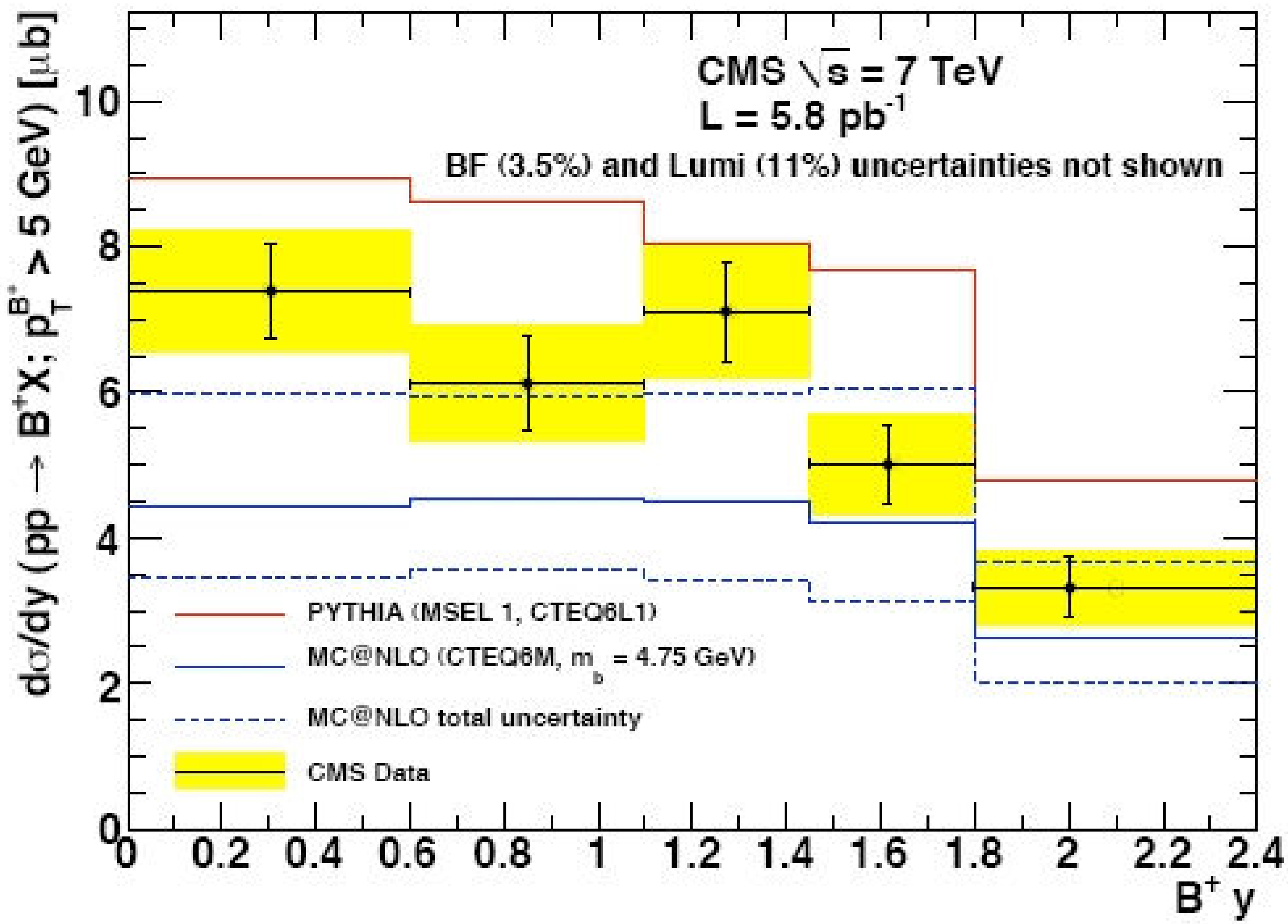




What are its Q. numbers? Kinematic characterisation of J/ψ?
Are there non-res final states or Open Charm production?

B Prodn. X-sec. @ CMS

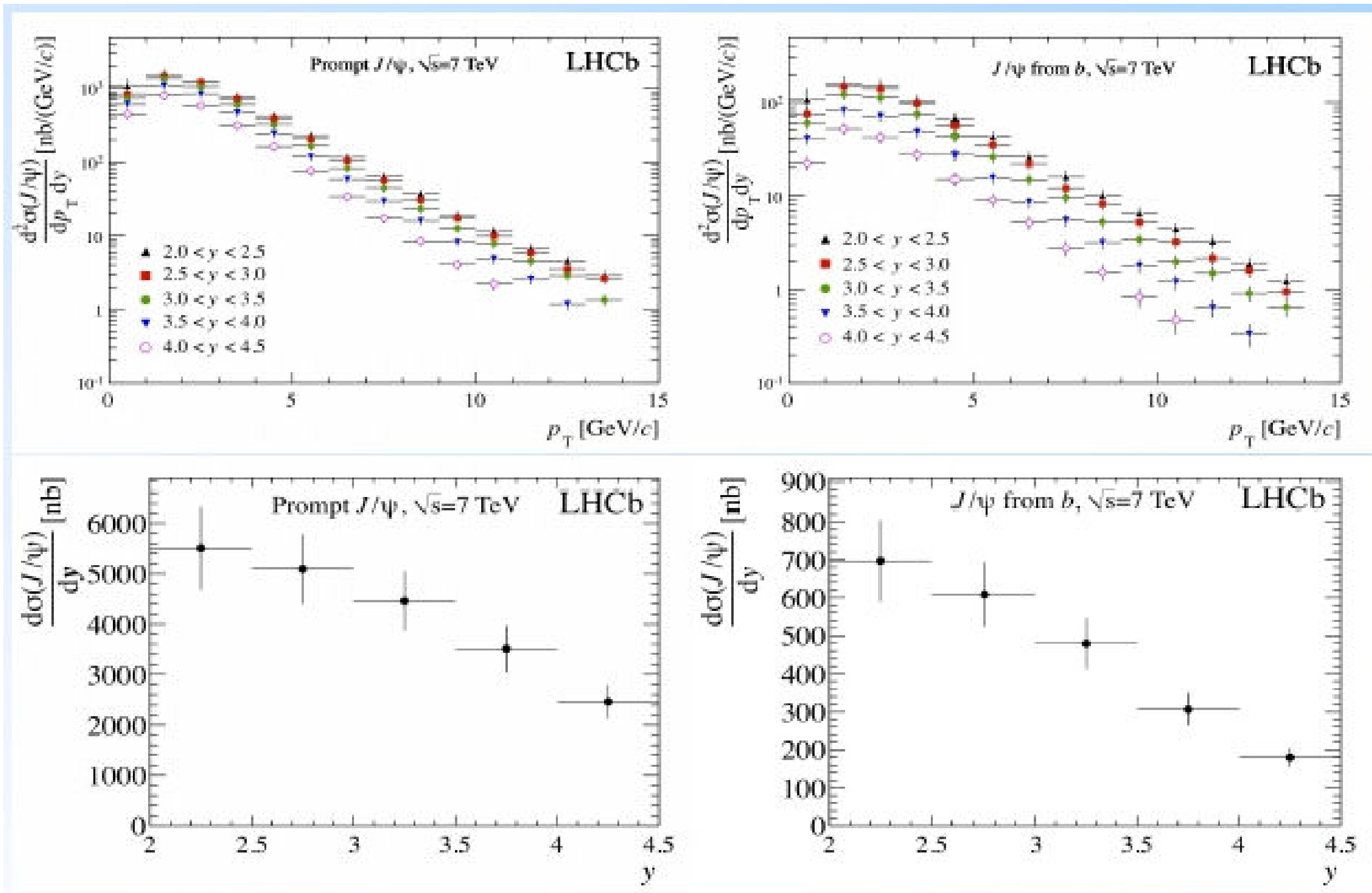
(Bouhover-Thacker)



But look at the MC uncertainties! (many more similar plots)

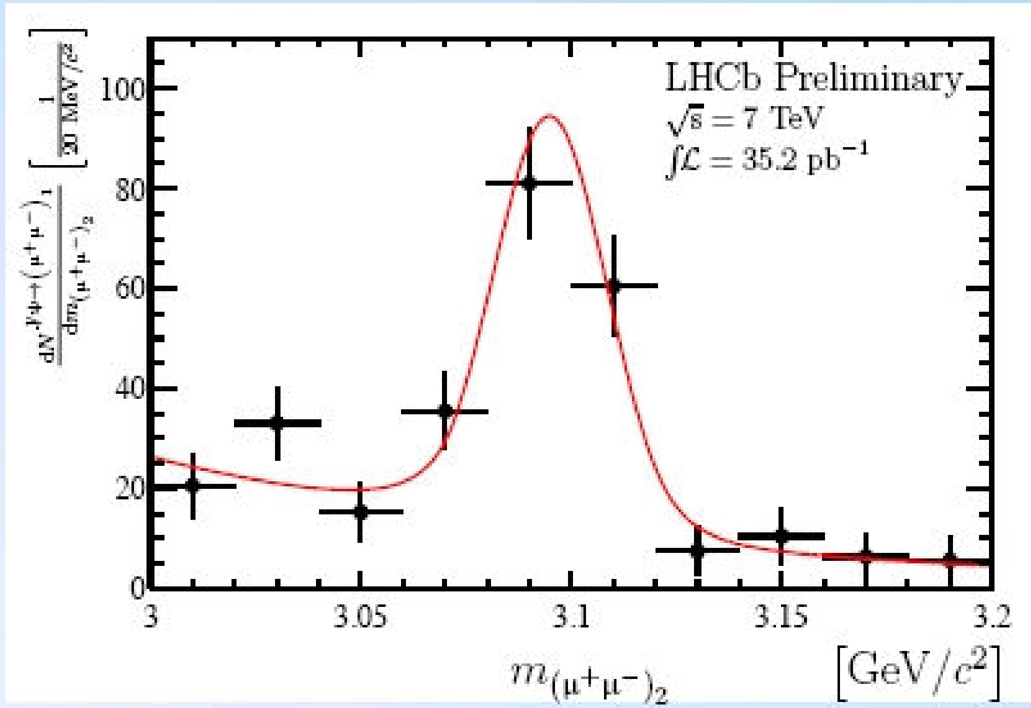
Results on Onia @LHC (Coccaro)

- Eg. J/ψ Prompt to non-Prompt ratio @LHCb



Allows estimate: $\sigma(pp \to b\bar{b}X) = 288 \pm 4 \pm 48\ \mu\mathrm{b}$ Cf. Theory?

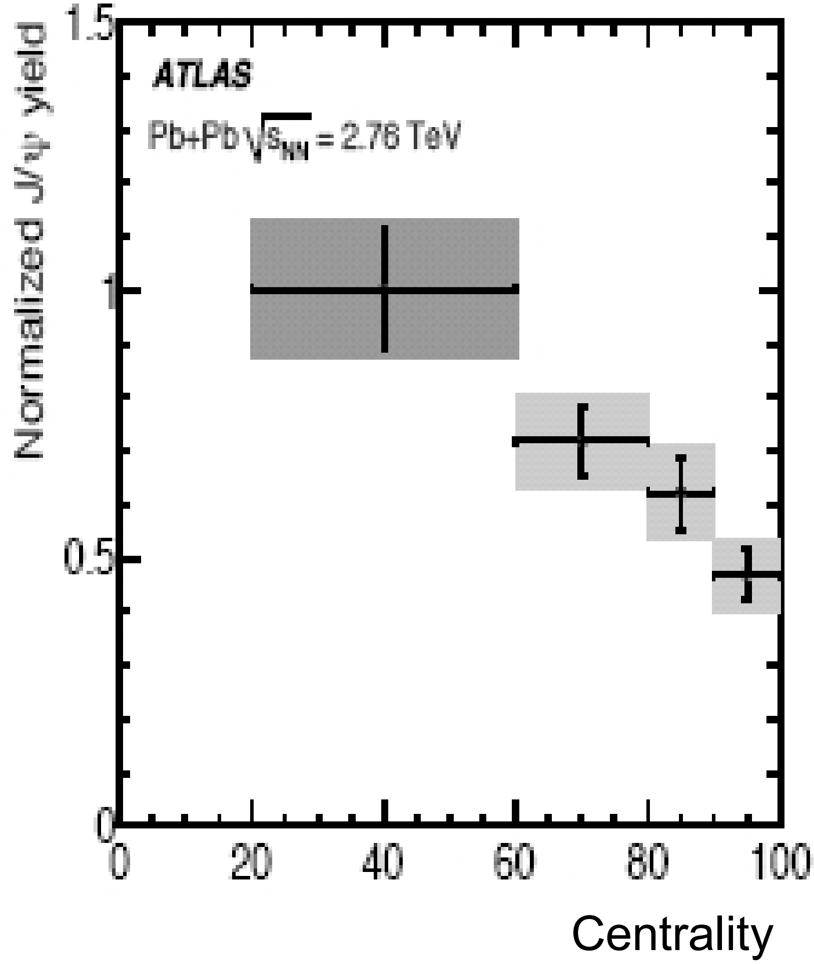
Double J/Ψ cross section (LHCb)



- integrated cross section $\sigma^{J/\Psi J/\Psi} = 5.6 \pm 1.1 \pm 1.2$nb
- theoretical prediction $\sigma^{J/\Psi J/\Psi} \sim 4.34$nb

No uncertainties quoted for theory prediction – presumably large?

J/ψ Centrality-dependent Suppression (ATLAS)



Effect predicted, but at what level?

Results on Onia@LHC (Coccaro)

- “No theory can simultaneously explain experimental measurements of both cross-section and polarisation”!!
- “Mechanism for quarkonia production and spin alignment to be understood”!!

Message of early data on HF production is that physics @LHC will tell us more about QCD than vice-versa.

Feldmann Reviewed Theory Status

1. Theory I (QCD and SM)
   - Factorization and Perturbative QCD Calculations
   - Inclusive B-meson decays
   - Exclusive Semi-leptonic B-Decays
   - Theory for $B \to K^{(*)}\mu^+\mu^-$ Decays
   - Charmless Non-Leptonic B-Decays
2. Theory II (Phenomenology and NP Models)
   - Right-handed currents
   - B-Meson Mixing
   - Exclusive Rare Semi-Leptonic B-Decays
3. Outlook

All relevant to decays.

Technology to calculate observables from parameters of SM (activities 1 and 2)

(Type 3 activity)

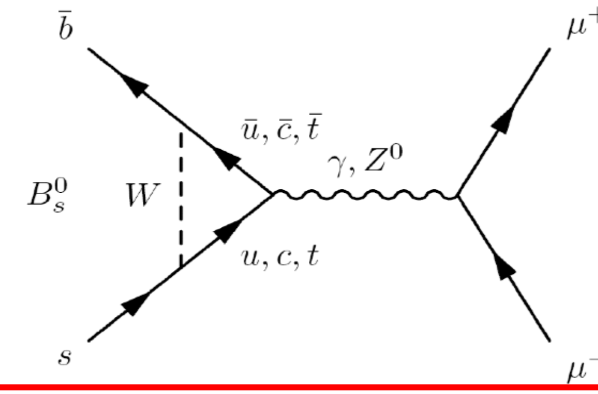
Rare B Decays @LHC (Elsasser)

Results for $B_s \to \mu^+\mu^-$: Predictive Power (I)

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

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

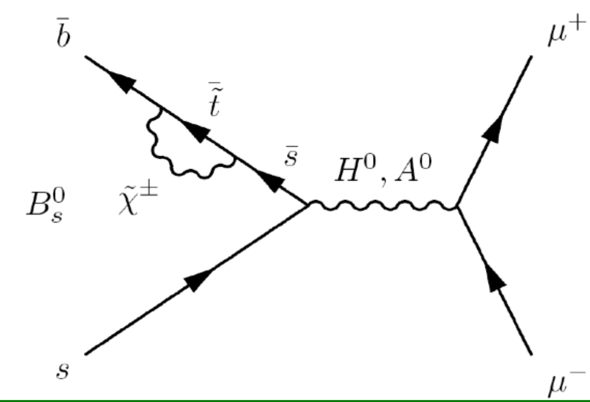
  [A.J.Buras,arXiv:1012.1447/Phys. Rev. D 80 (2009) 014503]



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

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

- Probing models with extended Higgs sector

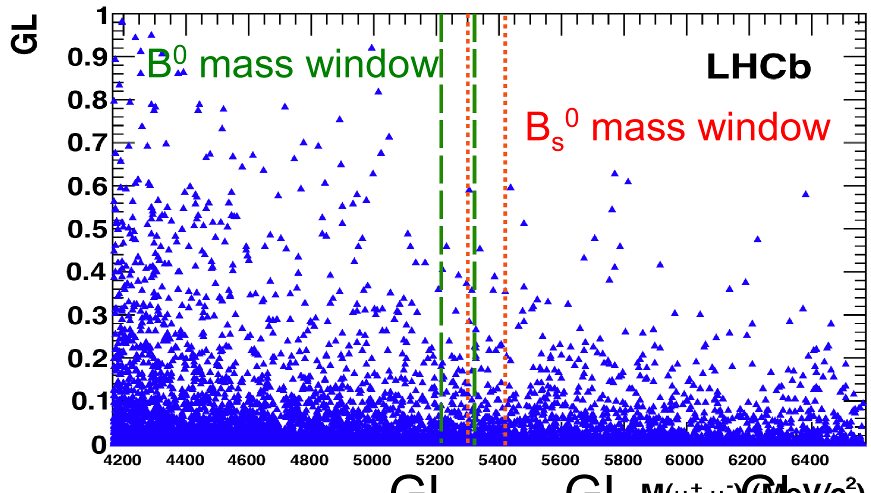


Worlds best limit for $BR(B_s \to \mu^+\mu^-)$ @ 95% CL: CDF: $4.3 \cdot 10^{-8}$ with 3.7 fb^{-1}

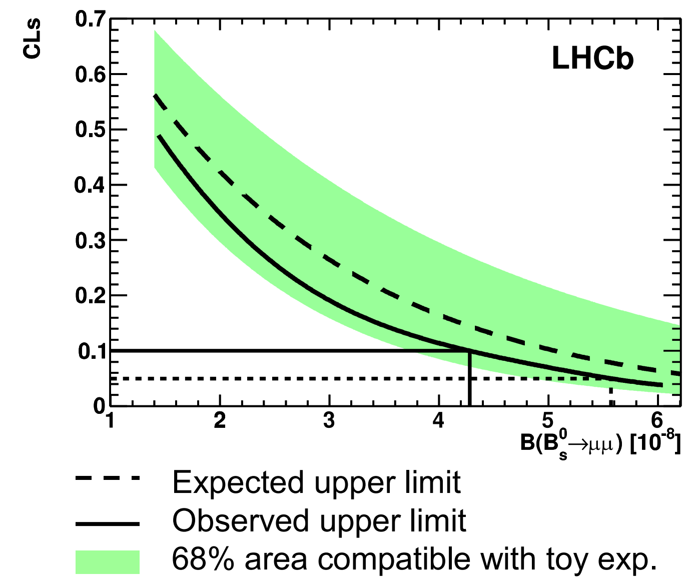
DØ: $5.1 \cdot 10^{-8}$ with 6.1 fb^{-1}

~~[Public CDF note 9892/Phys. Lett B 693, 593 (2010)]~~

Limit for $B_s \to \mu^+\mu^-$ (Elsasser)



$M(\mu\mu)-M_{Bs}$ [MeV/c²]	GL [0.00,0.25]	GL [0.25,0.50]	GL [0.50,0.75]	GL [0.75,1.00]
[-60,-40]	39	2	1	0
[-40,-20]	55	2	0	0
[-20,0]	73	0	0	0
[0,20]	60	0	0	0
[20,40]	53	2	0	0
[40,60]	55	1	0	0
Total	**335**	**7**	**1**	**0**
(Bkg exp)	329.1	7.4	1.53	0.080



$BR(B_s \to \mu^+\mu^-) < 5.6 \cdot 10^{-8}$

@ 95% CL

CDF: $4.3 \cdot 10^{-8}$ @ 95% CL with 3.7 fb^{-1}
[Public CDF note 9892]

DØ: $5.1 \cdot 10^{-8}$ @ 95% CL with 6.1 fb^{-1}
[Phys. Lett B 693, 593 (2010)]

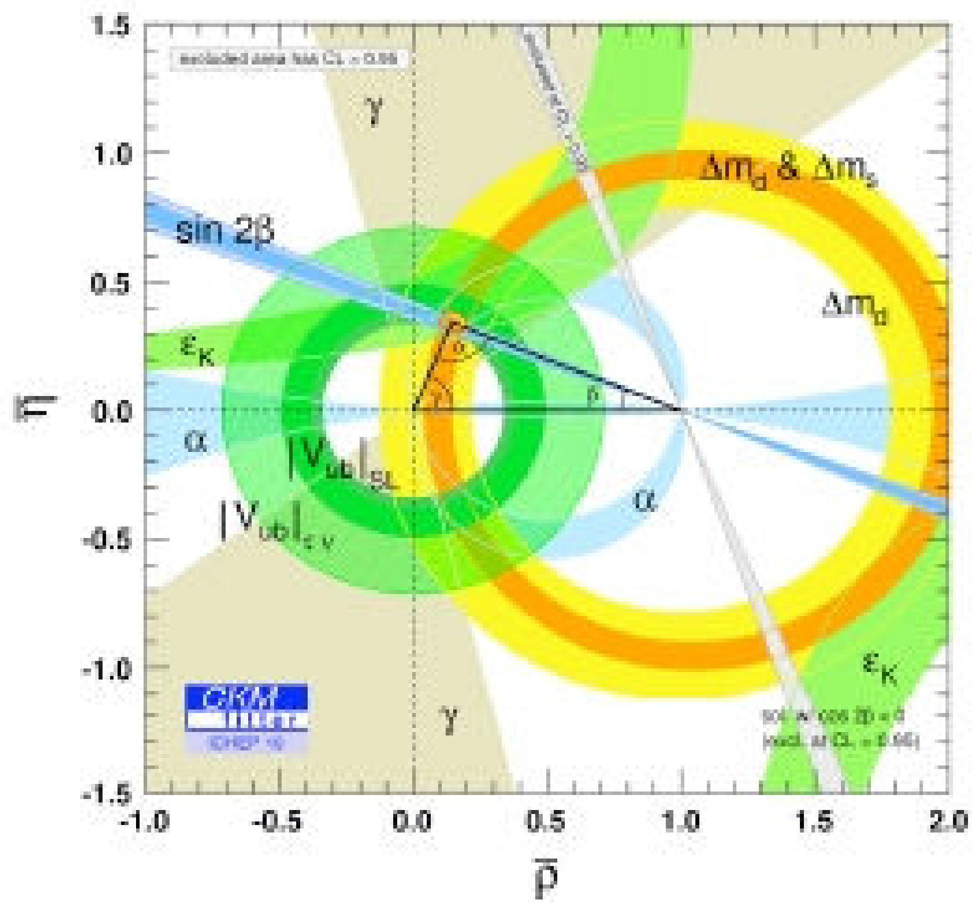
Many More Modes:

- B -> $K^*\mu^+\mu^-$
- B ->s γ
-
-

Since WI parameters well determined and calculations largely controlled, such decays are well predicted in SM, meaning measurements immediately sensitive to new physics.

Competitive sensitivities anticipated this year!

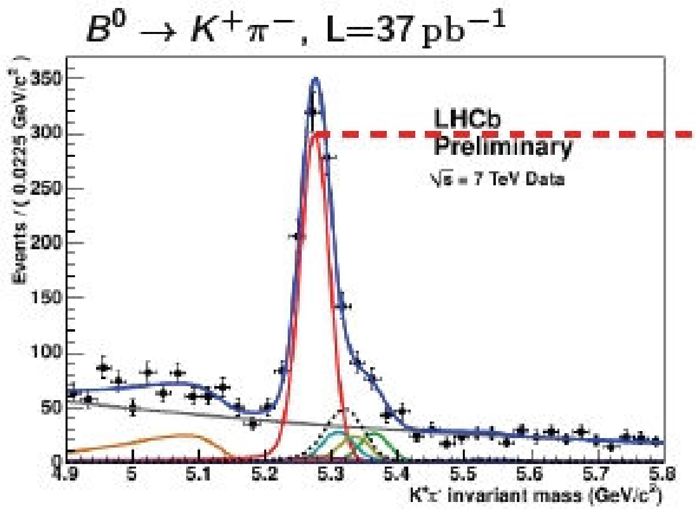
CPV@LHC (Brambach)

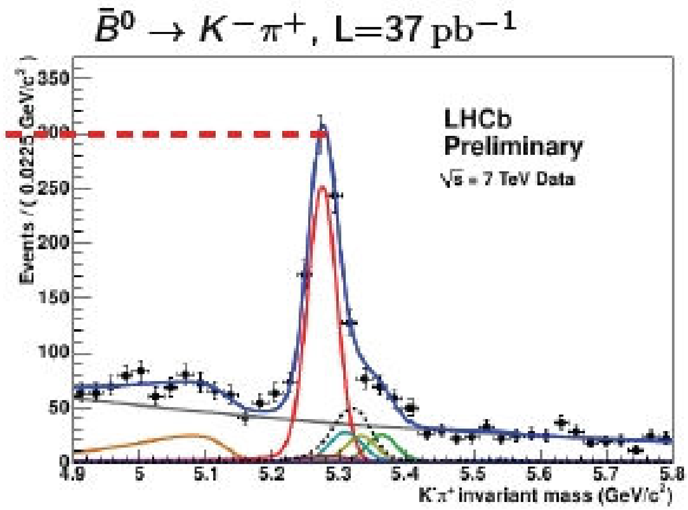


Similar story: after a decade @ B factories, SM parameters well-measured already.

Search is well underway @LHC to falsify SM

A first sign of CPV @ LHCb





	LHCb	world average
$A_{CP}(B^0 \to K^+\pi^-)$	$-0.077 \pm 0.033_{stat.} \pm 0.007_{syst.}$	-0.098 ± 0.012
$A_{CP}(B_s \to \pi^+K^-)$	$0.15 \pm 0.19_{stat.} \pm 0.02_{syst.}$	0.39 ± 0.17

- first observation of CPV @ LHCb
- interference of tree and penguin diagrams
- no γ measurement yet

LHCb CONF 2011-011

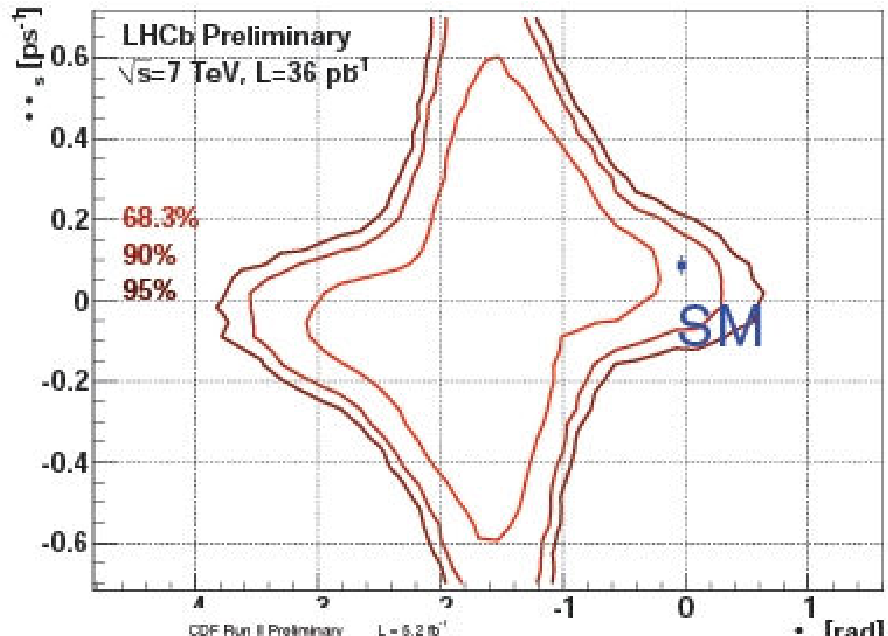
The quest for ϕ_S

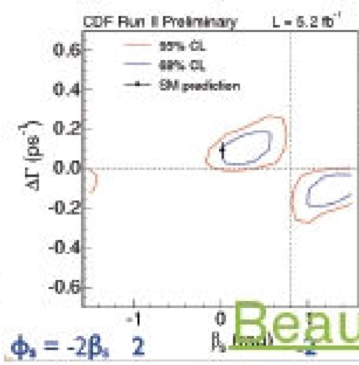
- measure lifetimes of B_d, B_u, B_s and Λ_b
  - LHCb CONF 2011-001
- do untagged measurement of ϕ_S on $B_s \rightarrow J/\psi\ \phi$
  - LHCb CONF 2011-002
- calibrate flavour tagging
  - LHCb CONF 2011-003
- measure sin 2β on $B_d \rightarrow J/\psi\ K_S$
  - LHCb CONF 2011-004
- measure Δm_d and Δm_s
  - LHCb CONF 2011-005 LHCb CONF 2011-010
- perform tagged analysis of $B_s \rightarrow J/\psi\ \phi$
  - LHCb CONF 2011-006

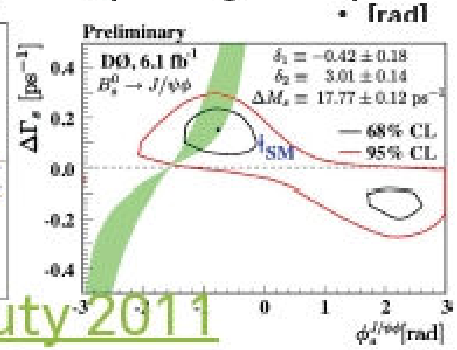
$B_s \rightarrow J/\psi\, \phi$

- first LHCb constraint on ϕ_s
- ambiguity reduced to two fold by use of tagging information
- systematics small compared to statistic uncertainties

$-2.7 < \phi_s < -0.5$ @ 68% CL







$\phi_s = -2\beta_s$

Beauty 2011

Big message from decays this week is that very soon, HF decays @LHC will become competitive as a Type 2 activity – testing the SM

Finally, a type 3 comment

- The SM has 3 sectors:
  - 3 Gauge interactions – “understood”
  - Higgs – λ and μ => SSB – not “understood”
  - 20 Yukawa coupling constants – govern flavour physics – completely not “understood”

- The Higgs and Yukawa sectors are determined by Ockam’s razor. They are the minimum one can think of consistent with gauge symmetry.

Comment (contd.)

- The experimentally determined Yukawa's display a startling degree of structure:
  - ~exponential mass hierarchies in quarks and charged leptons
  - CKM matrix for quarks is "nearly" diagonal
  - PMNS matrix for leptons is nearly tribimaximal
- These are all "accidental" in SM
- There is most surely NP beyond the SM which "determines" these structures.
- The NP must surely be revealed soon in explicit BSM signatures.