Experimental prospects for B physics and discrete symmetries at LHC and future projects

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University of Warwick

DISCRETE 2010
Symposium on Prospects in the Physics of Discrete Symmetries

6th December 2010

Experimental prospects …

and some motivations

… for B physics …

will also briefly mention charm and tau

… and discrete symmetries …

main focus on CP (a)symmetry & global symmetries

… at LHC …

mainly LHCb, some ATLAS & CMS

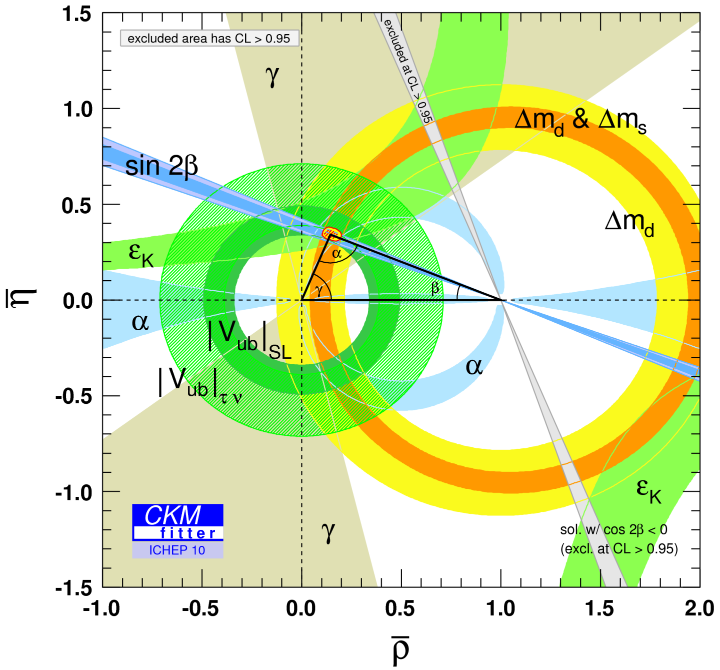
… and future projects

LHCb upgrade, Belle II, SuperB

Reminder – Current Status

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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



- CKM mechanism confirmed
  - All measurements of quark mixing & CP violation consistent with CKM paradigm
  - Several possible hints for effects of physics beyond the SM (A_{SL}, β_s, $K^*l^+l^-$, $B\to\tau\nu$)
  - Large contributions from new physics not excluded

CP violation scorecard

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

Observation with >5σ required for ✔

- Despite the huge progress made by the B factories, much remains to be experimentally tested
- Enormous discovery potential for next generation experiments

CP violation scorecard

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

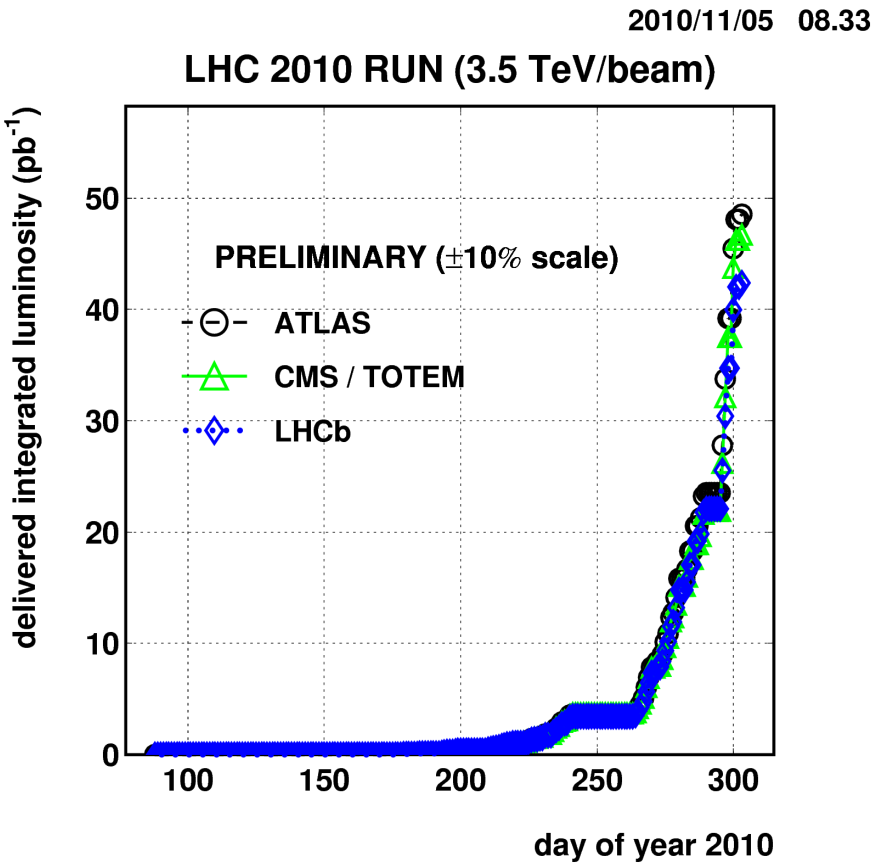
Observation with >5σ required for ✔

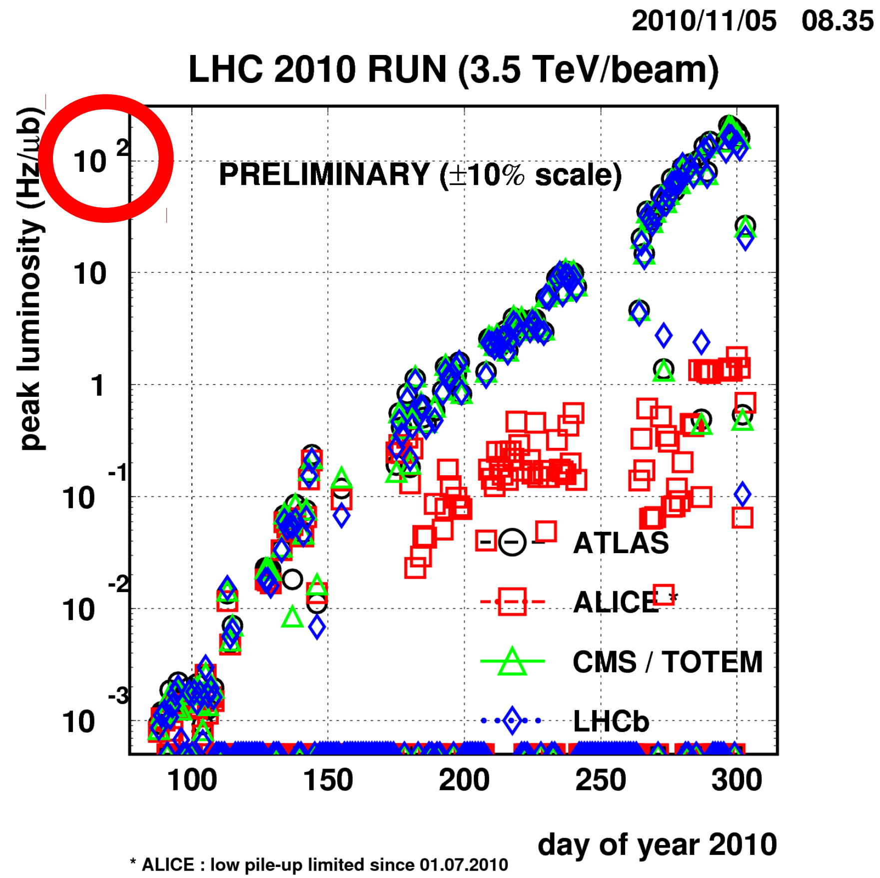
- sizeable effects expected in the Standard Model
- sensitive "null tests" of new physics effects

The Large Hadron Collider and its experiments

The LHC

LHC Performance 2010



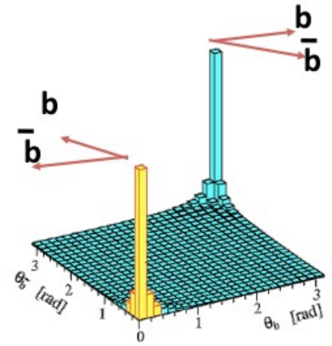


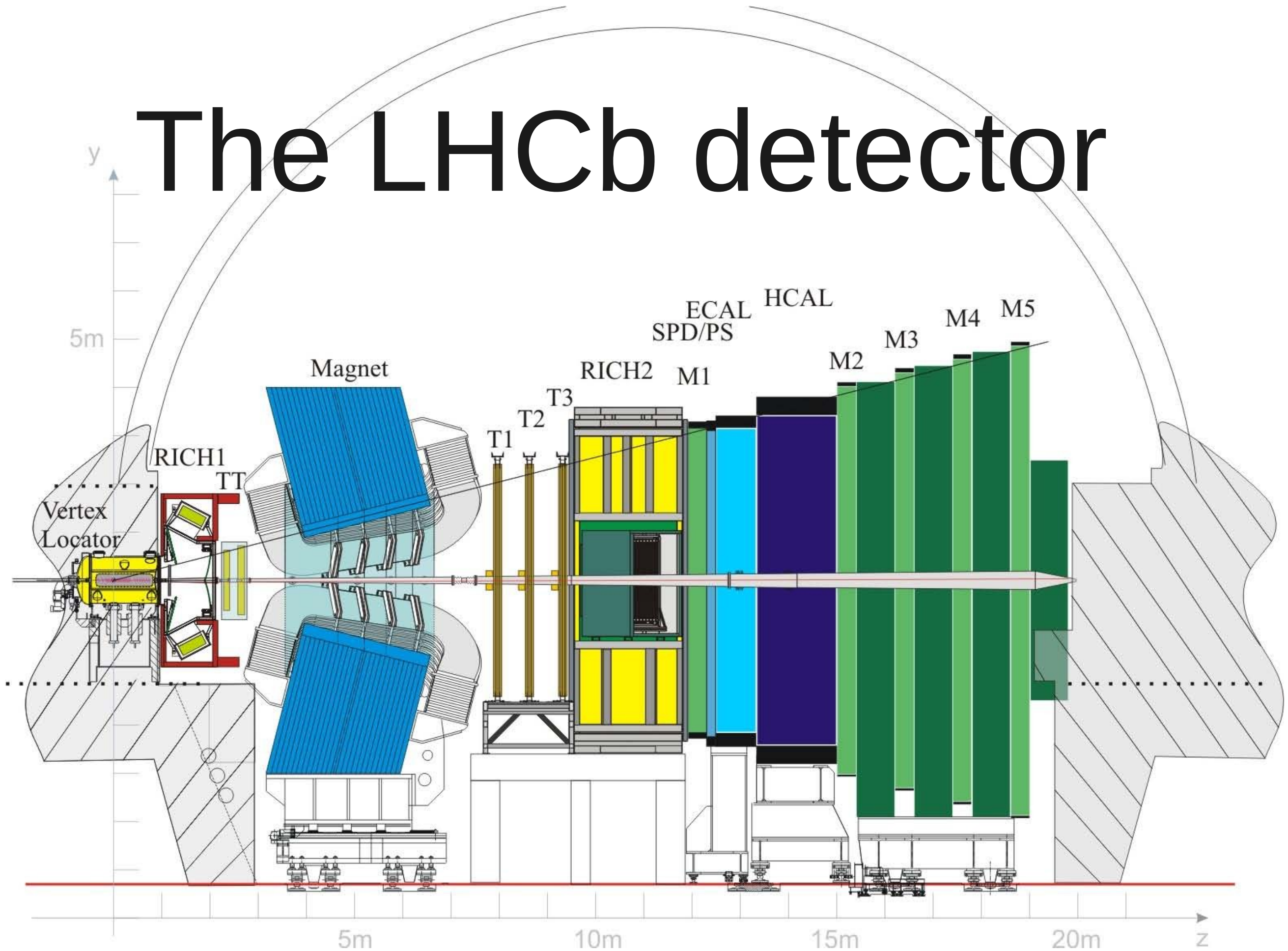
$\mathscr{L}_{peak} > 10^{32}/cm^2/s$

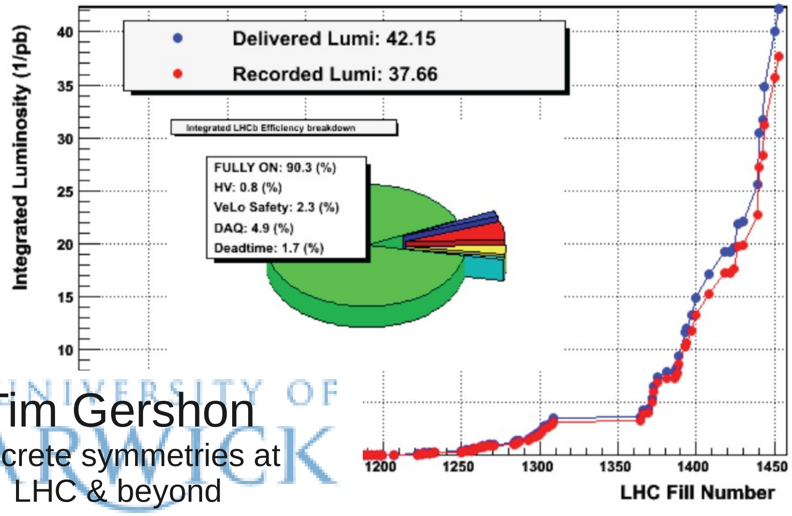
- achieved LHCb nominal luminosity

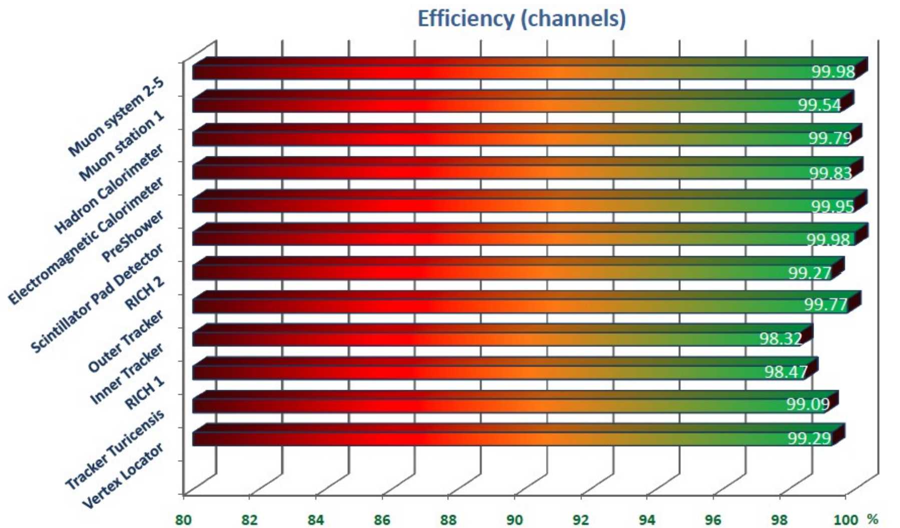
  (beam conditions however far from nominal)
- LHC design $10^{34}/cm^2/s$

The LHCb detector



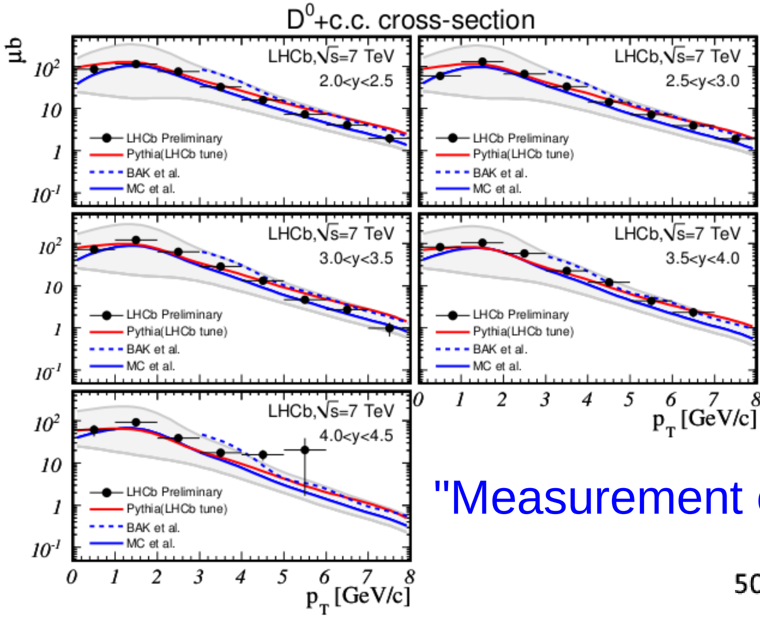




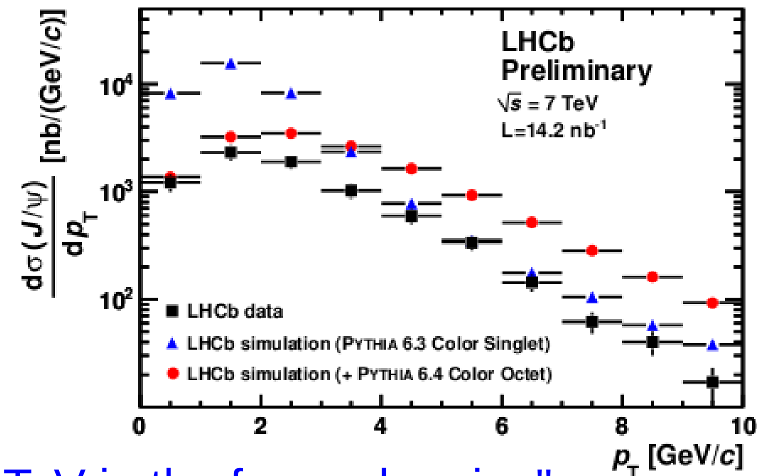


LHCb first physics

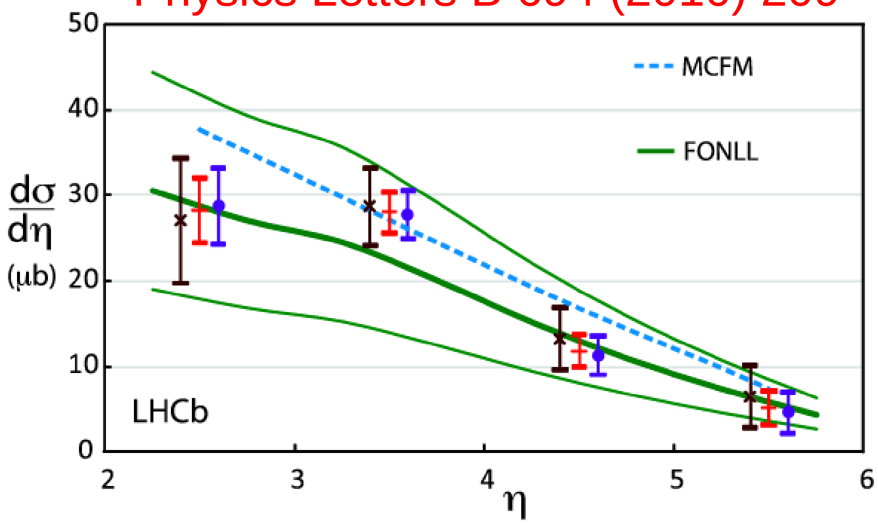
"Prompt charm production in pp collisions at √s = 7 TeV"
LHCb-CONF-2010-013



"Measurement of the J/ψ production cross-section at √s = 7 TeV in LHCb"
LHCb-CONF-2010-010



"Measurement of $\sigma(pp \to b\bar{b}X)$ at √s = 7 TeV in the forward region"
Physics Letters B 694 (2010) 209

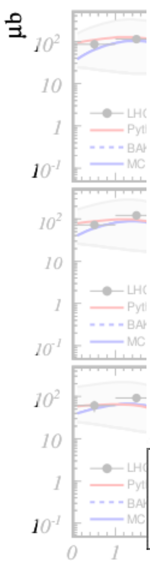


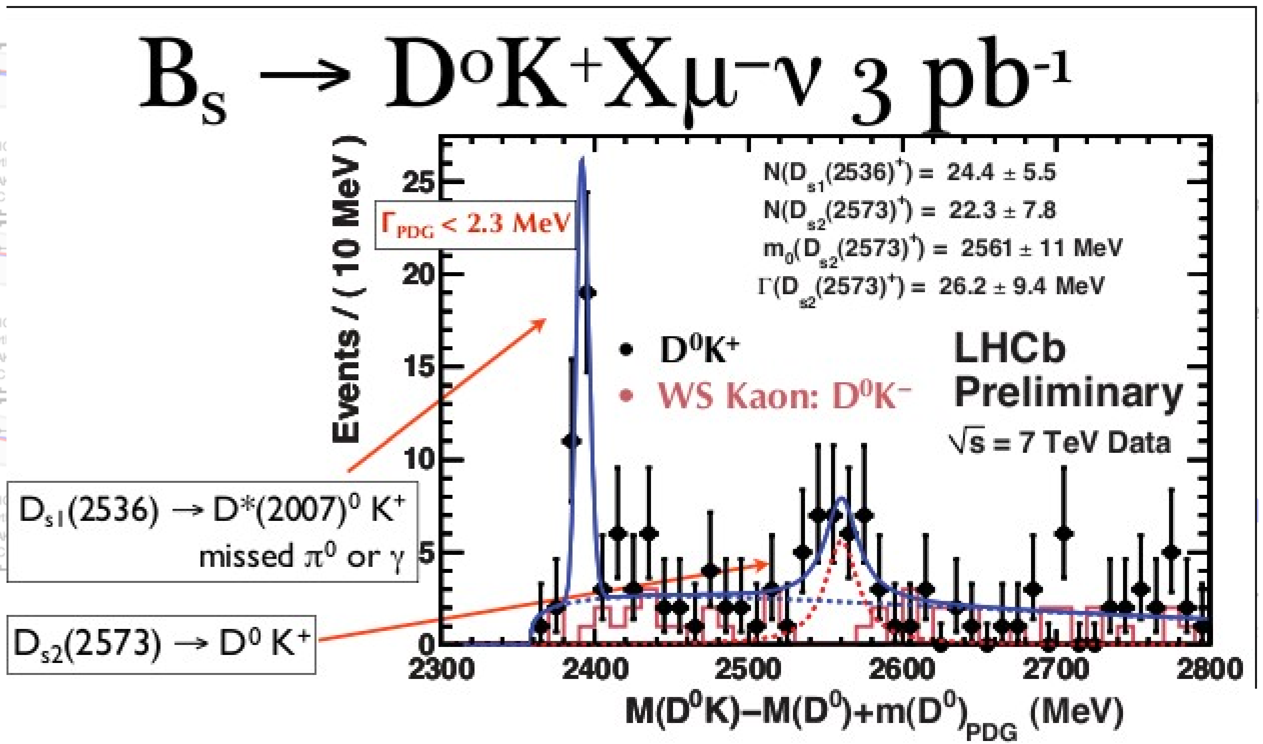
Tim Gershon
Discrete symmetries at LHC & beyond

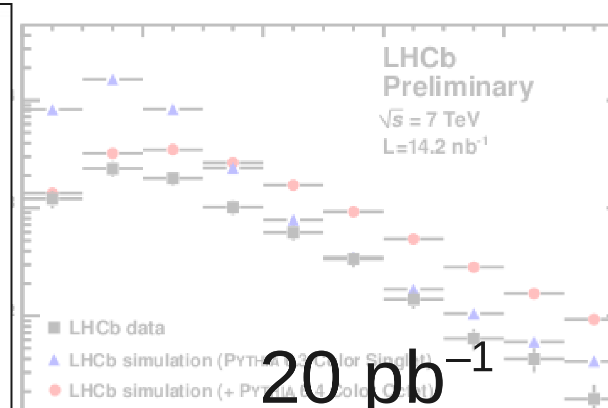
LHCb first physics

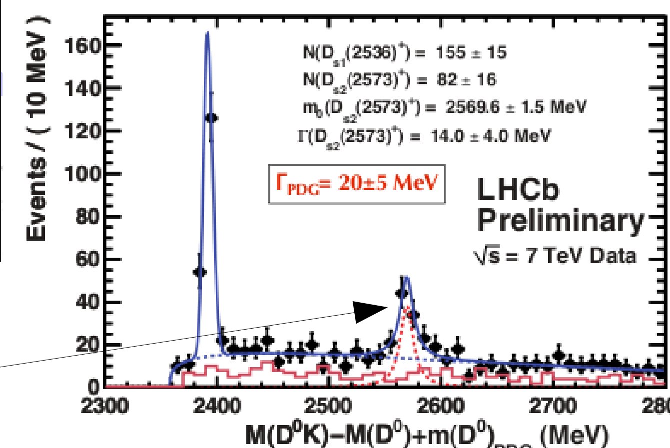
“Pron ... ıction ... .HCb”

Hot news! First observation of $B_s \to D_{s2}^{*} X \mu\nu$



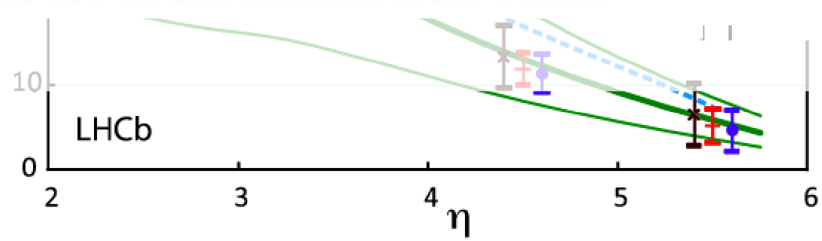




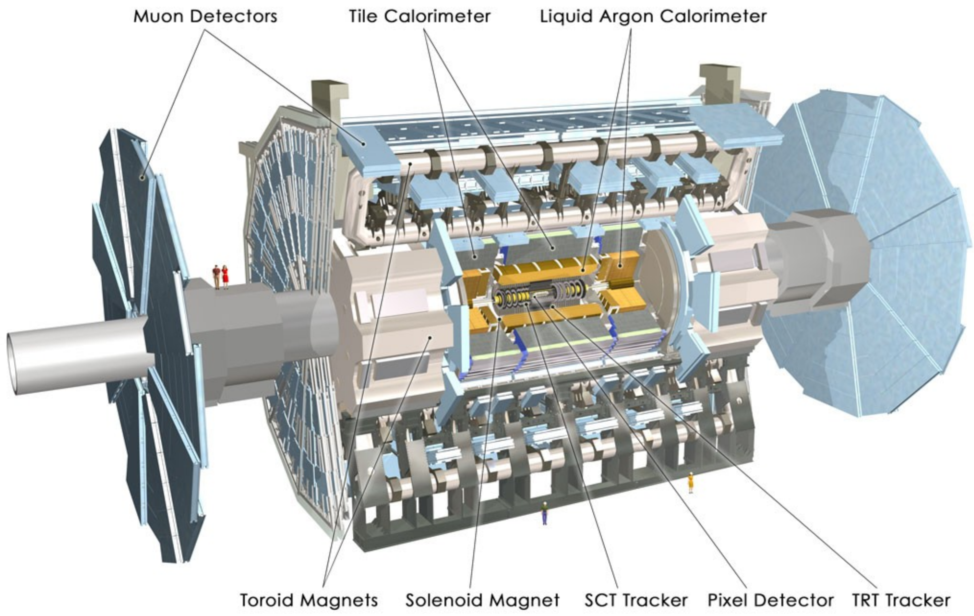


D0 observed $B_s \to D_{s1}(2536)^+\mu\nu$, $D_{s1}(2536)^+ \to D^{*+} K^0$ [PRL 102 051801]

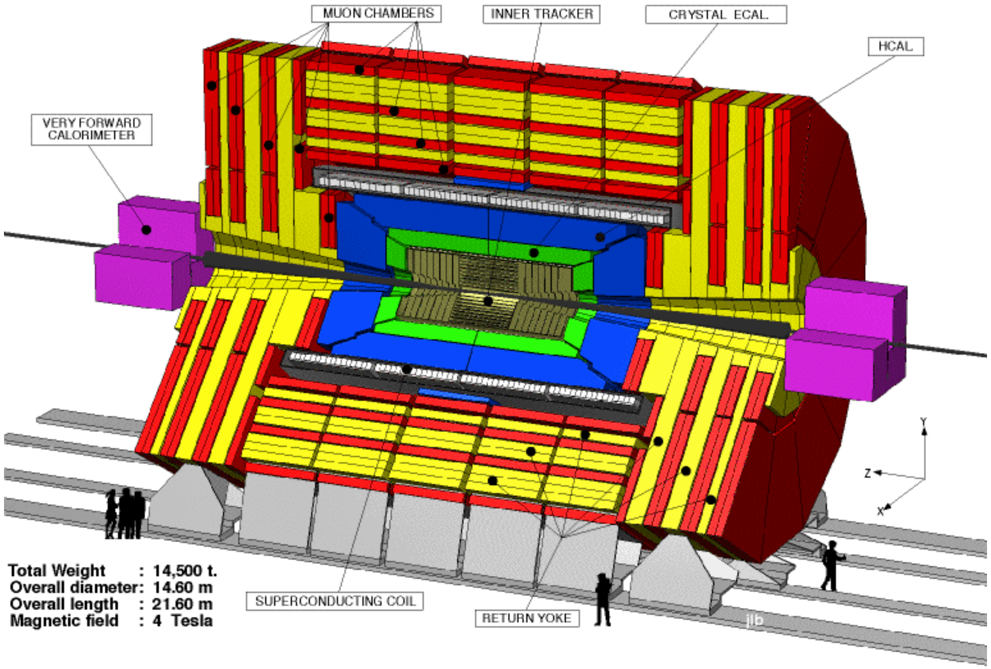
Nobody has seen $B_s \to D_{s2}(2536)^+\mu\nu$ before. We used more data to confirm it.



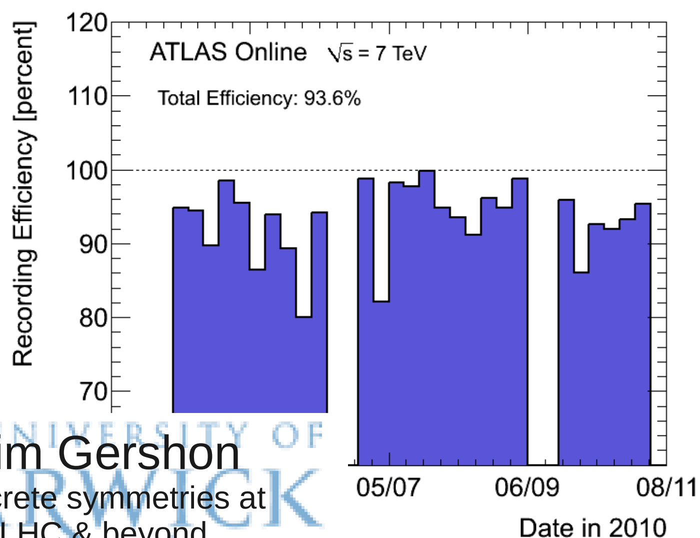
ATLAS & CMS



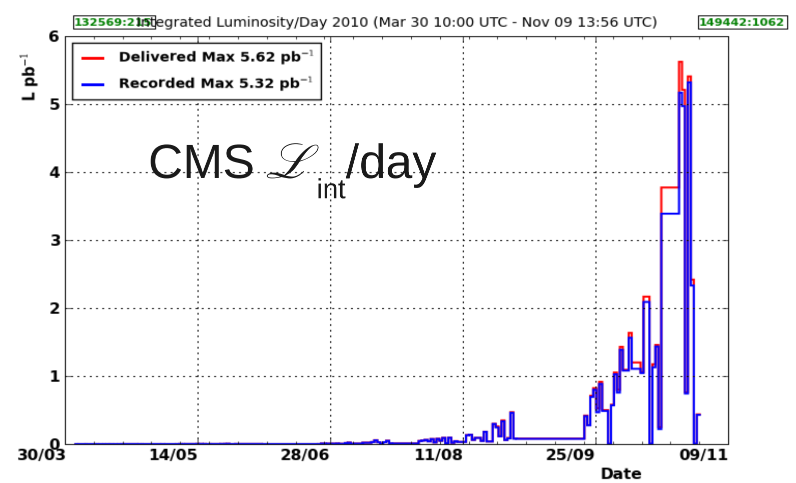
Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker



MUON CHAMBERS
INNER TRACKER
CRYSTAL ECAL
HCAL
VERY FORWARD CALORIMETER
SUPERCONDUCTING COIL
RETURN YOKE
Total Weight : 14,500 t.
Overall diameter: 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla



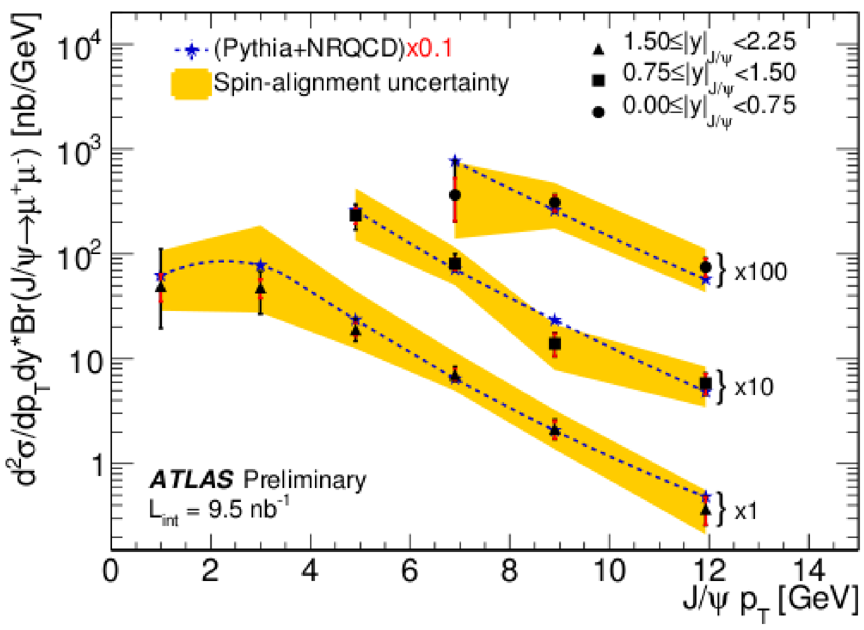
ATLAS Online $\sqrt{s}$ = 7 TeV
Total Efficiency: 93.6%
Recording Efficiency [percent]
120
110
100
90
80
70
05/07
06/09
08/11
Date in 2010



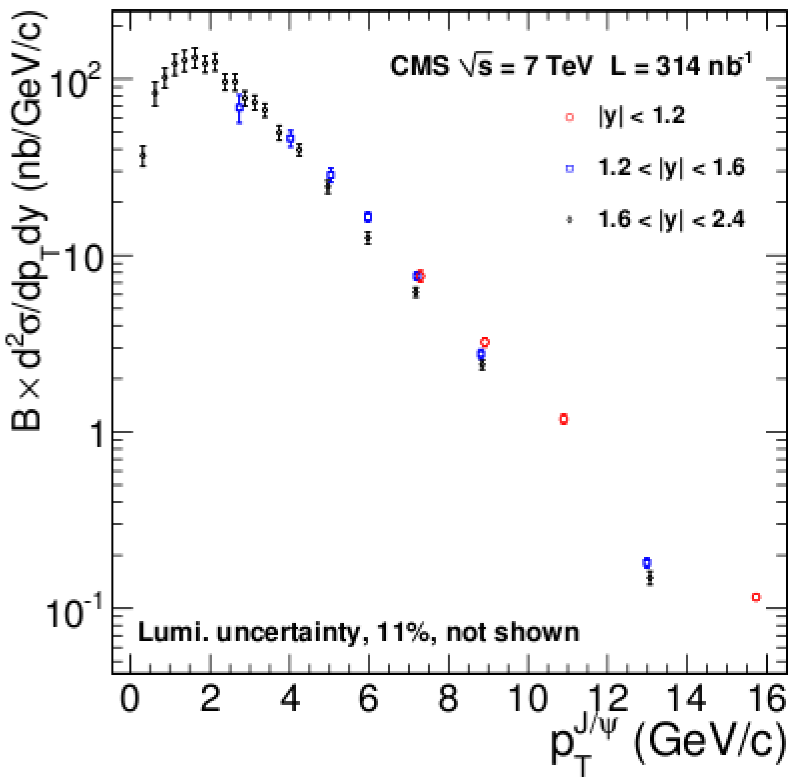
Integrated Luminosity/Day 2010 (Mar 30 10:00 UTC - Nov 09 13:56 UTC)
Delivered Max 5.62 pb^{-1}
Recorded Max 5.32 pb^{-1}
L pb^{-1}
CMS $\mathscr{L}_{int}$/day
30/03
14/05
28/06
11/08
25/09
09/11
Date

ATLAS & CMS first physics

"A first measurement of the differential cross section for the $J/\psi \to \mu^+\mu^-$ resonance and the non-prompt to prompt J/ψ cross section ratio with pp collisions at $\sqrt{s}$ = 7 TeV in ATLAS"
ATLAS-CONF-2010-062



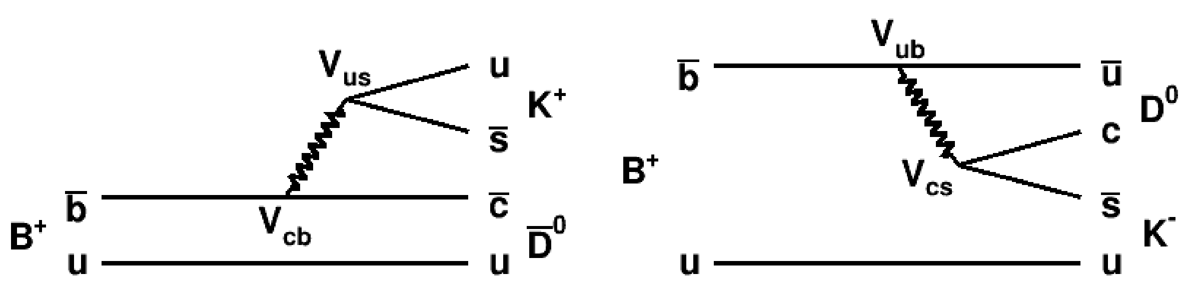
"Prompt and non-prompt J/ψ production in pp collisions at $\sqrt{s}$ = 7 TeV"
CMS-BPH-10-002, arXiv:1011.4193

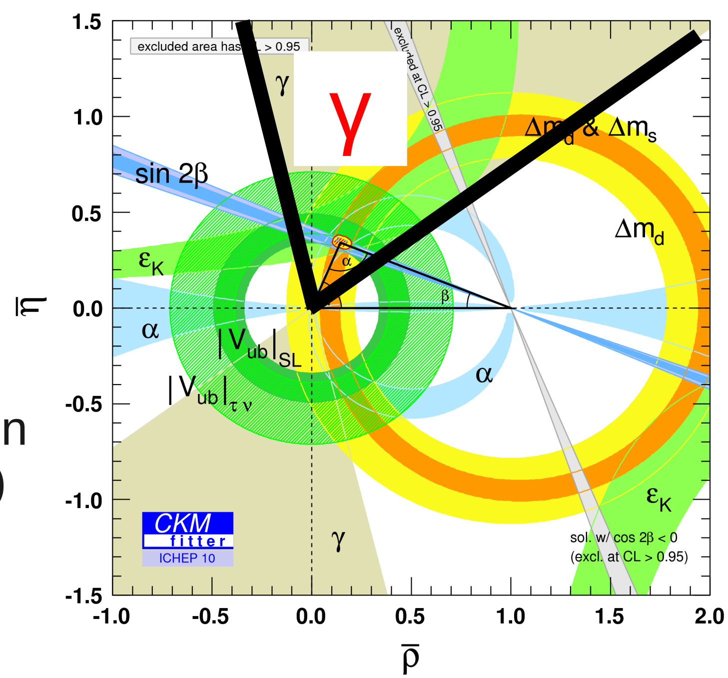


CP violation effects expected in the Standard Model

Measurement of γ from $B^{\pm} \rightarrow DK^{\pm}$

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

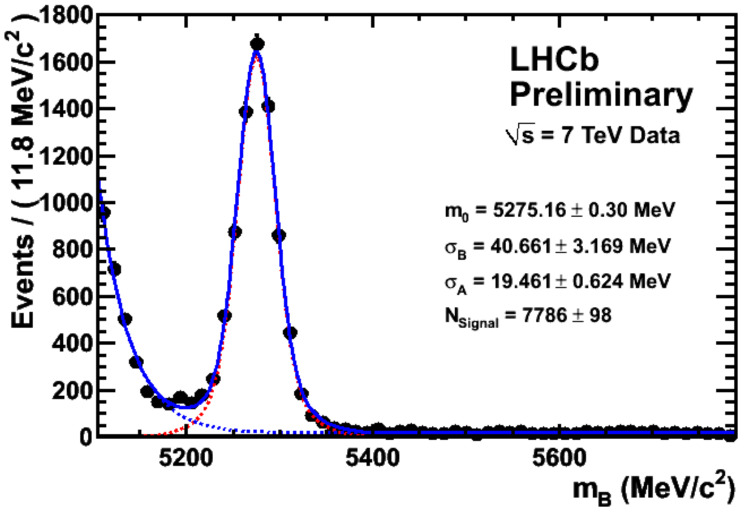




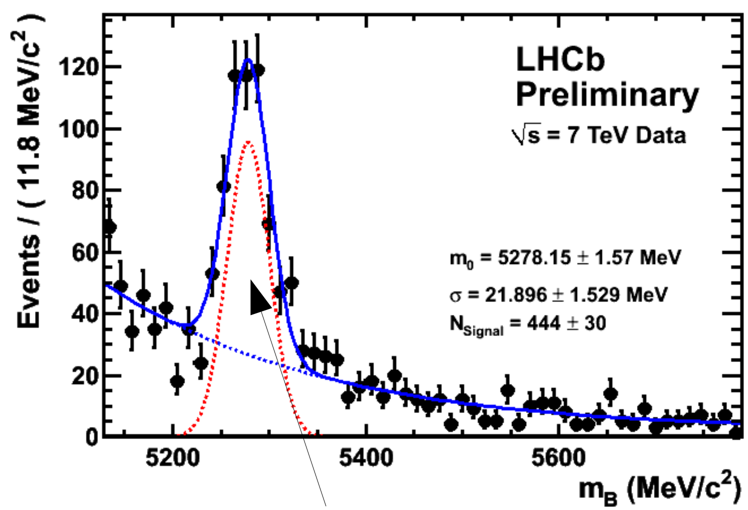
Interference between tree amplitudes gives CP violation effects that depend on their weak phase difference (γ)

LHCb yields in $B^{\pm} \to D\pi^{\pm}$ & $B^{\pm} \to DK^{\pm}$

$B^{\pm} \to D\pi^{\pm}$ with $D \to \pi K$

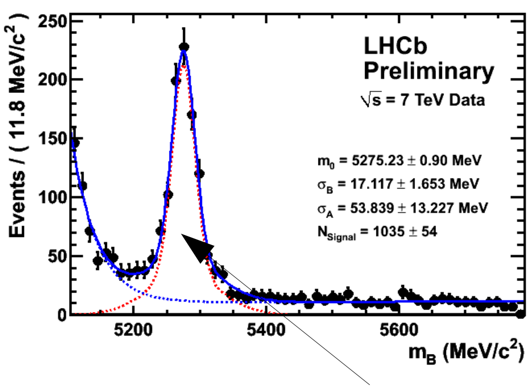


$B^{\pm} \to DK^{\pm}$ with $D \to \pi K$

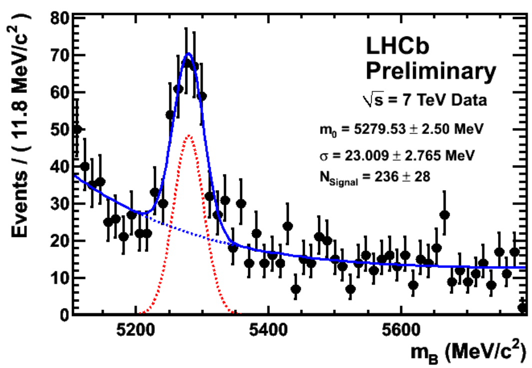


LHCb yield with ~34/pb : 444 ± 30
c.f. CDF with 1/fb : 516 ± 37

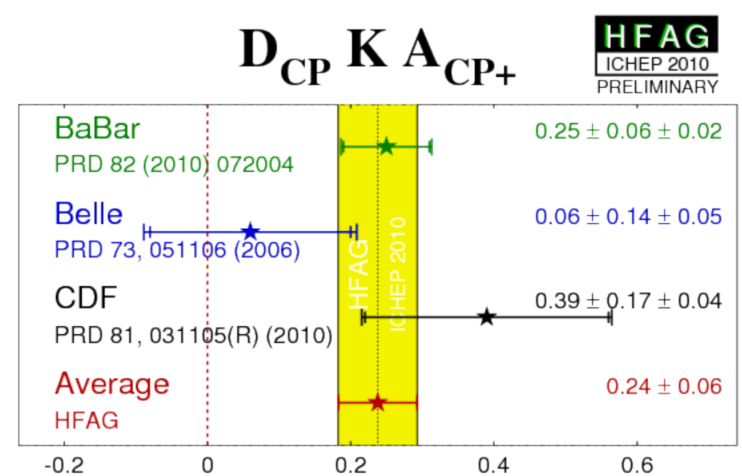
$B^{\pm} \to D\pi^{\pm}$ with $D \to KK$



$B^{\pm} \to D\pi^{\pm}$ with $D \to \pi\pi$



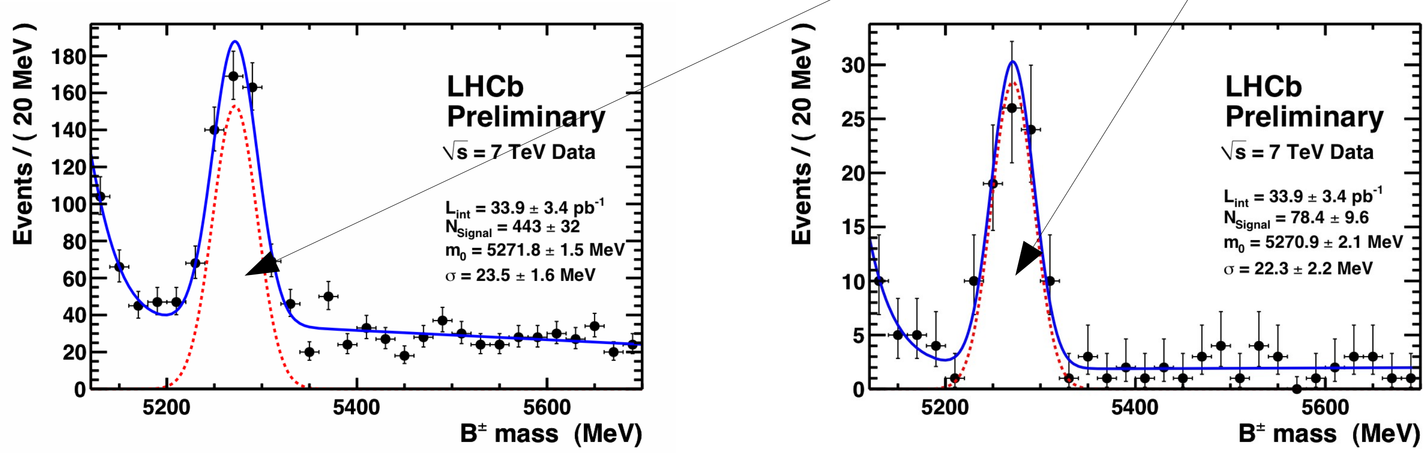
LHCb yield with ~34/pb : 1035 ± 54
c.f. CDF with 1/fb : 780 ± 36



Prospects for direct CP violation measurement in charged B decays

- Expect to observe >5σ effect in $B^{\pm} \to D_{CP} K^{\pm}$ with 1/fb
- Excellent prospects also in $B^{\pm} \to D_{sup} K^{\pm}$ (ADS analysis) and $B^{\pm} \to D_{Dalitz} K^{\pm}$

Signals for $(K_s \pi^+ \pi^-)\pi^{\pm}$ and $(K_s K^+ K^-)\pi^{\pm}$ in ~34/pb

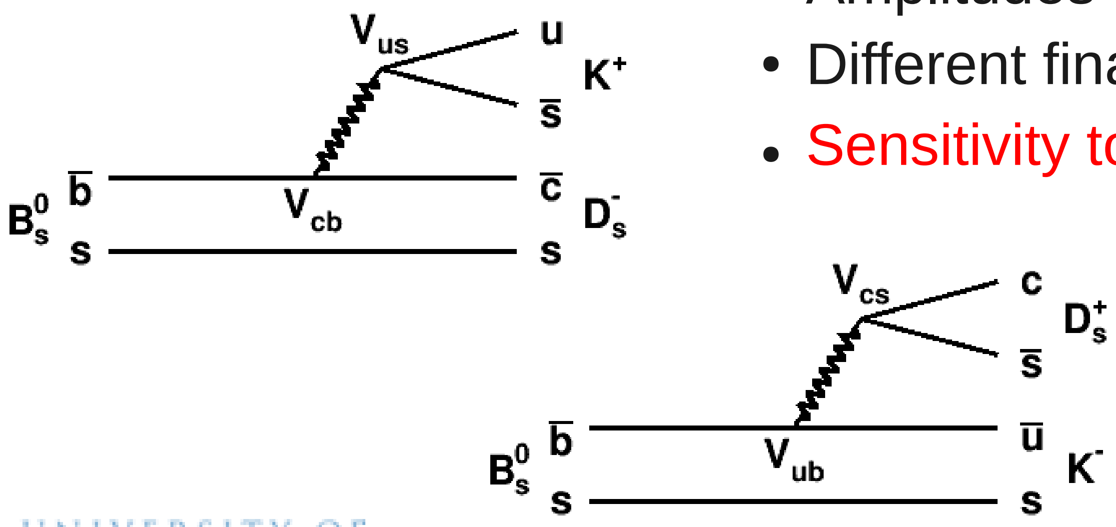


- Several other possibilities for the first observation: for example $B^{\pm} \to \rho^0 K^{\pm}$ (in $B^{\pm} \to \pi^+ \pi^- K^{\pm}$ Dalitz plot analysis)

Measurement of γ from $B_s \to D_s K$

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

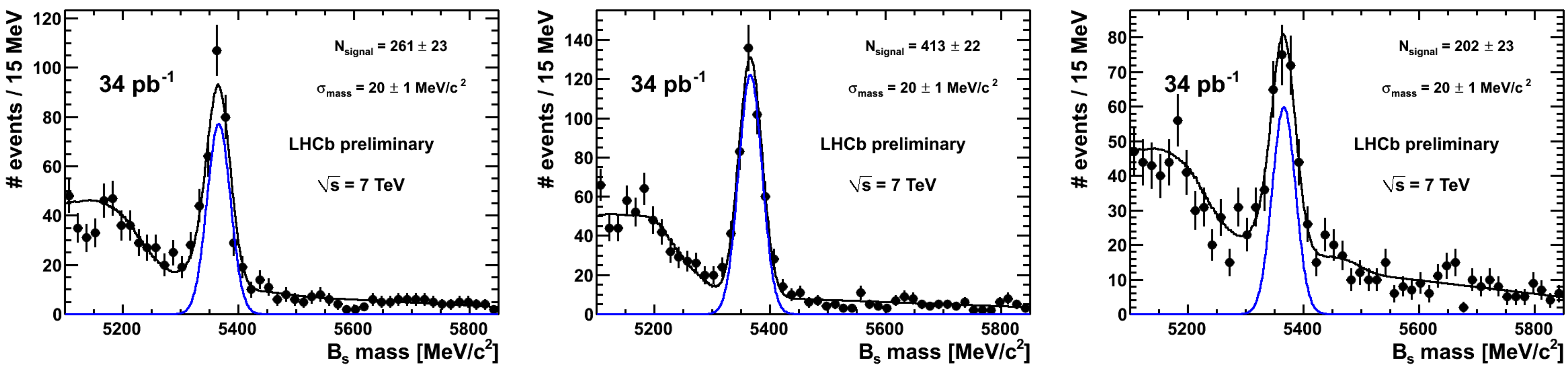
- Amplitudes with weak phase difference γ
- Different final states, interfere via mixing
- Sensitivity to $\gamma - 2\beta_s$



Prospects for γ measurement from $B_s \to D_s K$

- Large signals for $B_s \to D_s \pi$ (used for Δm_s measurement)

$B_s \to D_s \pi$; $D_s \to \varphi\pi$ $B_s \to D_s \pi$; $D_s \to K^*K$ $B_s \to D_s \pi$; $D_s \to KK\pi$ (other)



- $B_s \to D_s K$ final state under study
- Expect world's first time-dependent analysis in 2011

Combined sensitivity to γ from B → DK

- Estimated sensitivity described in LHCb roadmap document arXiv:0912.4179
- Nominal conditions (14 TeV, $\mathscr{L}$ = 2 10^{32}/cm^2/s)

Table 11: Expected combined sensitivity to γ from $B \to DK$ and time-dependent measurements for data sets corresponding to integrated luminosities of 0.5 and 2 fb^{-1}. The table is taken from Ref. [9]. In these studies the Level-0 and Level-1, a precursor to HLT1, triggers were included. The HLT2 trigger was not included.

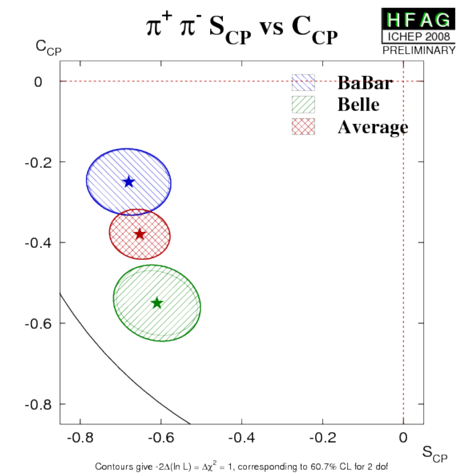
δ_{B^0} (°)	0	45	90	135	180
σ_γ for 0.5 fb^{-1} (°)	8.1	10.1	9.3	9.5	7.8
σ_γ for 2 fb^{-1} (°)	4.1	5.1	4.8	5.1	3.9

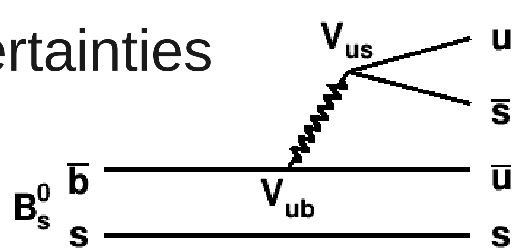
- At 7 TeV, σ(b$\bar{\text{b}}$) is lower by a factor of about 2
- Estimated sensitivity of ~7° with 2011 data

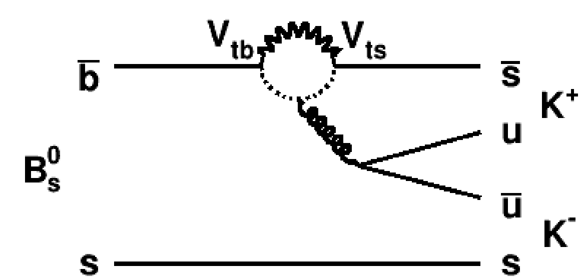
Measurement of γ from $B_s \to K^+K^-$

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

- Relative weak phase between two leading amplitudes is γ
- If tree amplitude dominates, mixing-induced CP violation is sensitive to 2γ-$2\beta_s$
- But additional amplitudes also contribute
- U-spin relation to $B_d \to \pi^+\pi^-$ provides input to constrain hadronic uncertainties

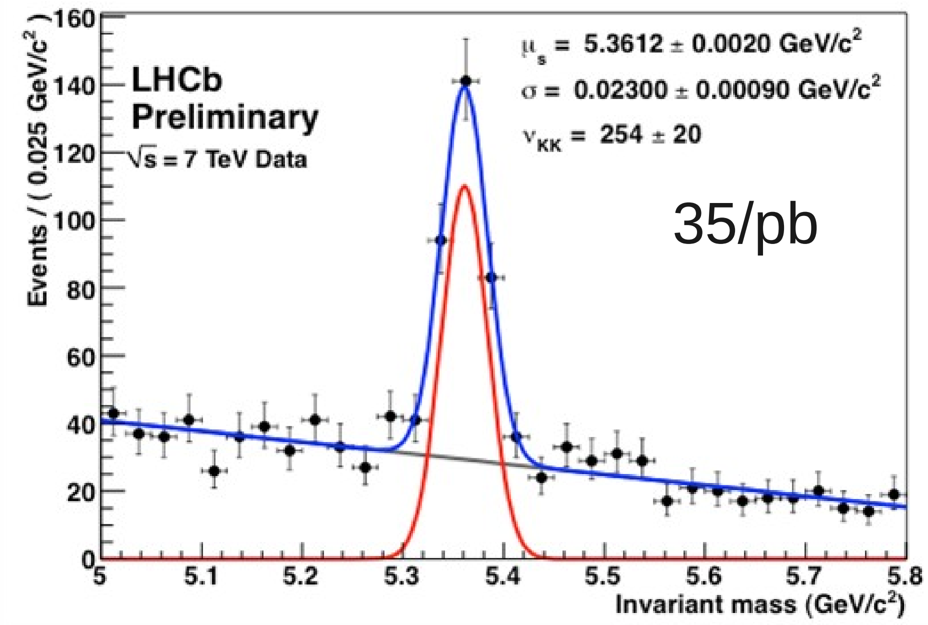




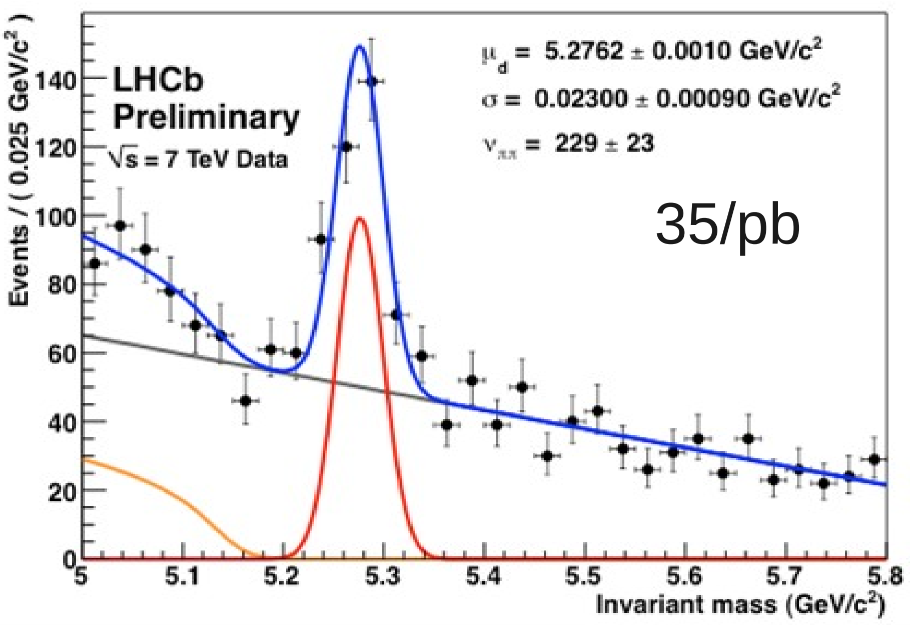


Prospects for γ measurement from $B_s \to K^+K^-$

$B_s \to K^+K^-$



$B_d \to \pi^+\pi^-$



- LHCb yields in ~35/pb: 254±20 $B_s \to K^+K^-$ & 229±23 $B_d \to \pi^+\pi^-$
  - c.f. CDF in 1/fb: 1307±64 $B_s \to K^+K^-$ & 1121±63 $B_d \to \pi^+\pi^-$
- Expect first time-dependent measurements in 2011
  - (including measurement of B_s lifetime in CP-even K^+K^- final state)

Search for direct CP violation in $B_{d/s} \to K^+\pi^-$

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

Compilation of CP Asymmetries for B^0 modes

In PDG2010 New since PDG2010 (preliminary) New since PDG2010 (published)

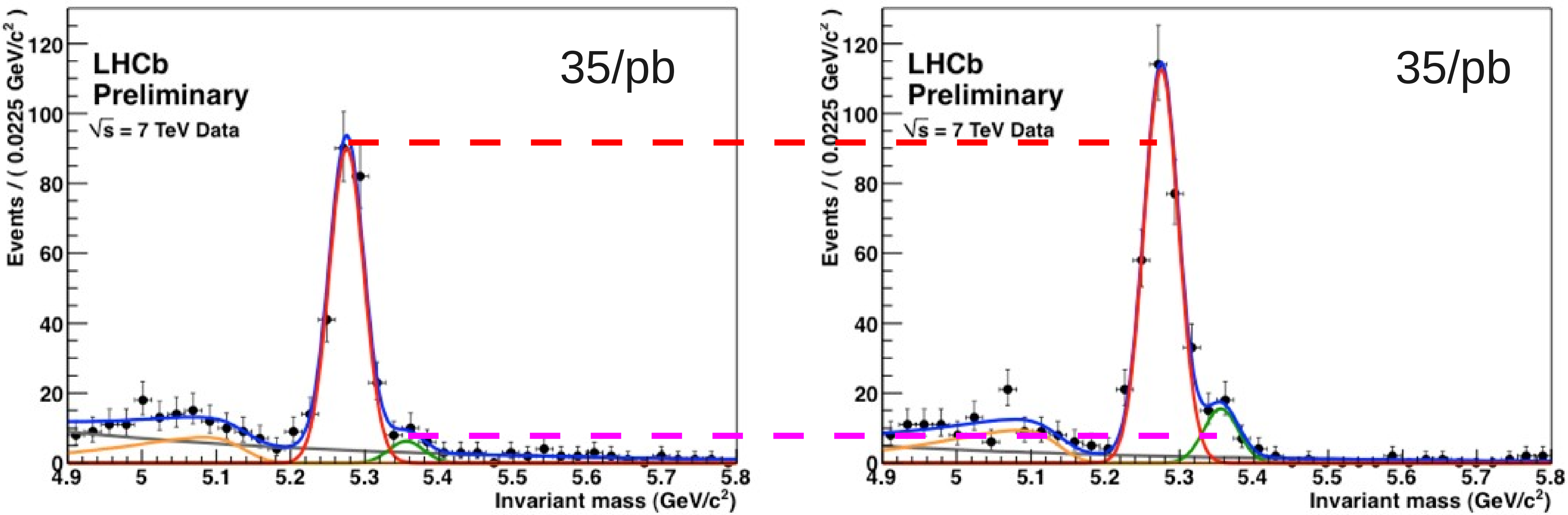
RPP#	Mode	PDG2010 Avg.	BABAR	Belle	CLEO	CDF	New Avg.
210	$K^+\pi^-$	-0.098 ± 0.013	$-0.107 \pm 0.016^{+0.006}_{-0.004}$	$-0.094 \pm 0.018 \pm 0.008$	$-0.04 \pm 0.16 \pm 0.02$	$-0.086 \pm 0.023 \pm 0.009$	$-0.098^{+0.012}_{-0.011}$

Compilation of CP Asymmetries for B_s modes

RPP#	Mode	PDG2010 Avg.	BABAR	Belle	CLEO	CDF	New Avg.
22	$K^+\pi^-$	New				$0.39 \pm 0.15 \pm 0.08$	0.39 ± 0.17

Prospects for direct CP violation in $B_{d/s} \rightarrow K^+\pi^-$

$\overline{B}^0_{d/s} \rightarrow K^-\pi^+$ $\qquad$ $B^0_{d/s} \rightarrow K^+\pi^-$

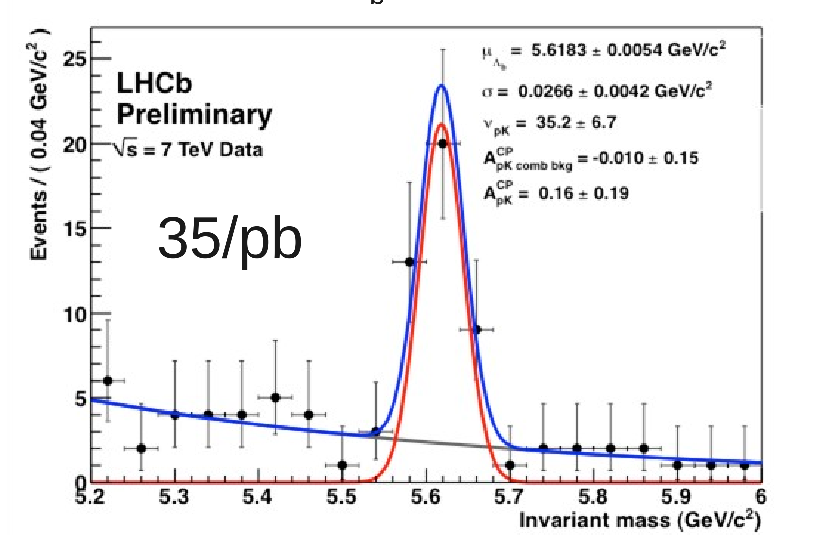


- Raw asymmetries clearly visible in existing data
- Central values consistent with expectations & previous measurements
- Calibration and evaluation of systematic uncertainties in progress

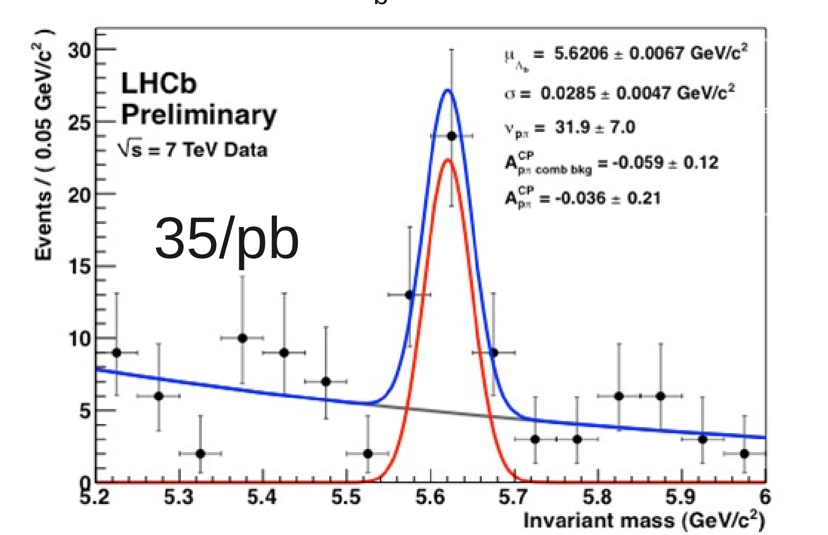
Search for CP violation in Λ_b decay

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

$\Lambda_b \to pK$



$\Lambda_b \to p\pi$

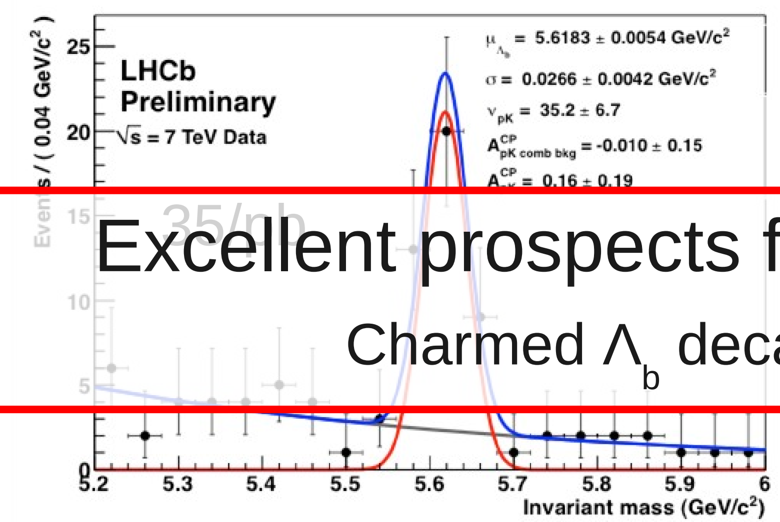


Warning: numbers are raw (uncorrected) and with statistical uncertainties only

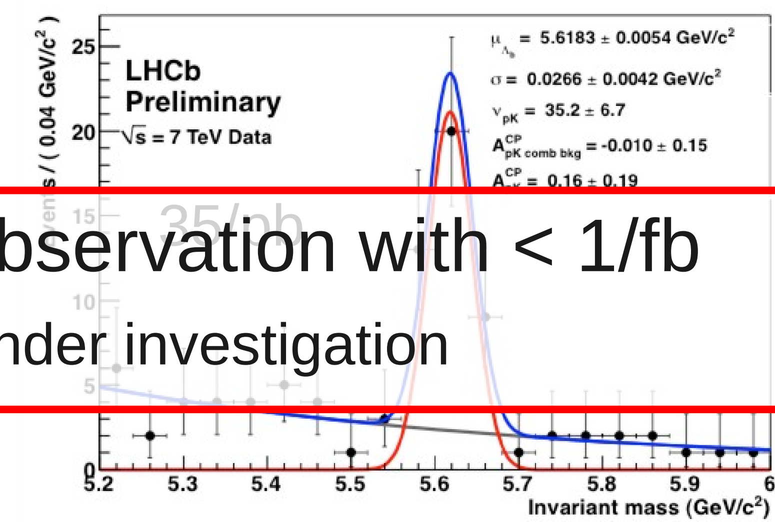
Search for CP violation in Λ_b decay

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

$\Lambda_b \to pK$



$\Lambda_b \to p\pi$



Excellent prospects for A_{CP} observation with < 1/fb

Charmed Λ_b decays also under investigation

Warning: numbers are raw (uncorrected) and with statistical uncertainties only

CP violation effects

not expected in the Standard Model

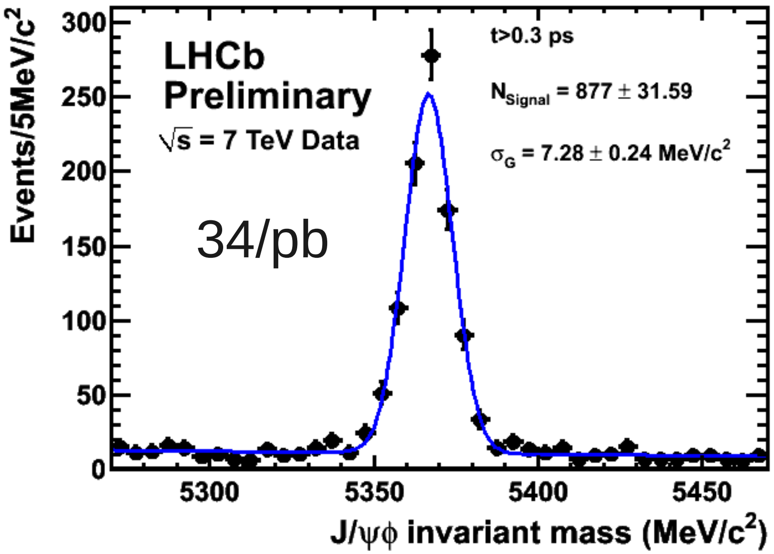
Measurement of $2\beta_s$ from $B_s \to J/\psi\phi$

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

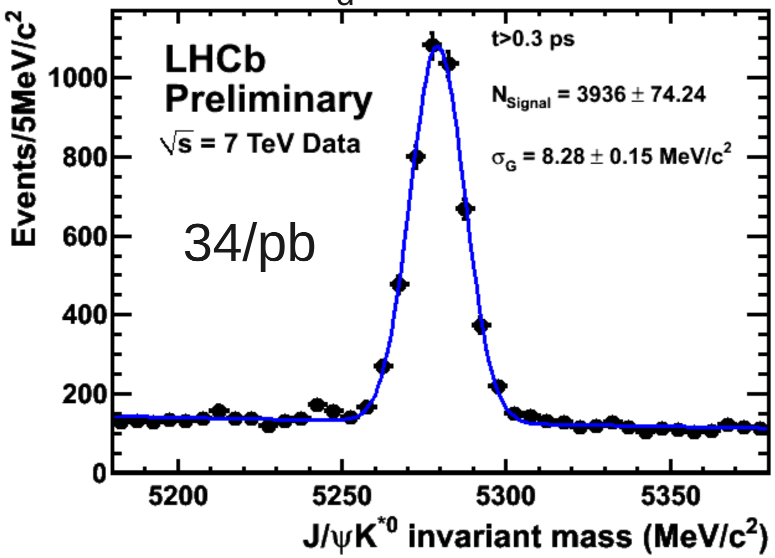
- Similar "golden mode" to $B_d \to J/\psi K_S$ except …
  - vector-vector final state – requires angular analysis to separate CP-even and CP-odd components
  - width difference $\Delta\Gamma_s$ cannot be neglected
  - CP violating phase of B_s oscillations is small in the Standard Model
- Exciting hints of non-standard effects in CDF and D0 results

Prospects for $B_s \to J/\psi\phi$

$B_s \to J/\psi\phi$



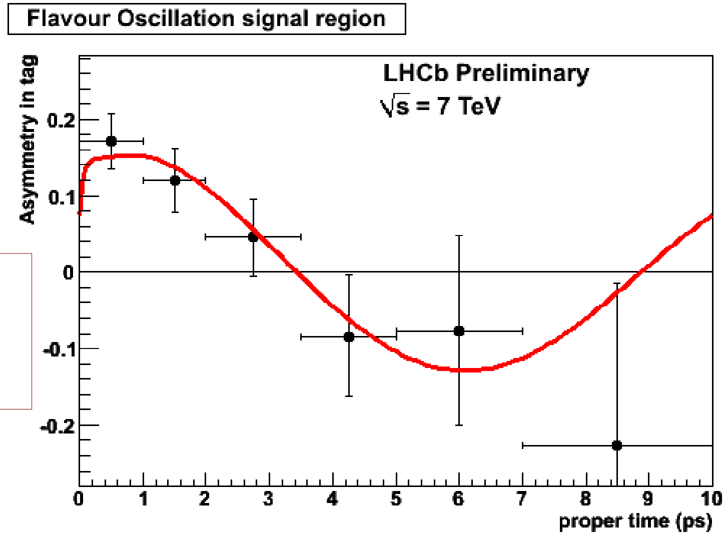
$B_d \to J/\psi K^{*0}$



877 ± 32 $B_s \to J/\psi\phi$ events in 34/pb

- c.f. CDF ~6500 in 5.2/fb
- c.f. D0: ~3500 in 6.1/fb

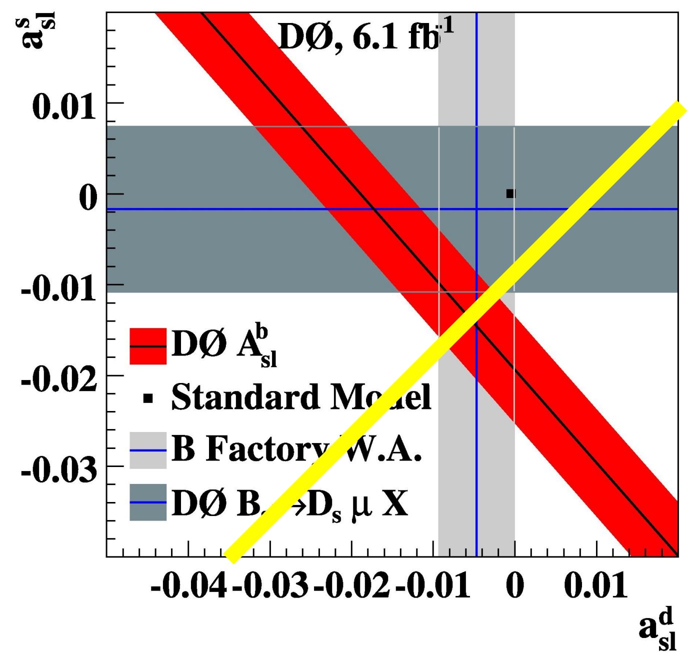
Oscillations seen in $B_d \to D^*\mu\nu X$ with 1.9/pb



Search for CP violation in B oscillations

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

- Semileptonic decays ideal to probe CP violation in mixing
- Inclusive like-sign dileptons → combination of effects from B_d and B_s
- Alternative approach: study difference of effects in $B_d \rightarrow D^+\mu\nu X$ and $B_s \rightarrow D_s^+\mu\nu X$
  - use both D^+ and D_s^+ decays to KKπ so that most systematics cancel

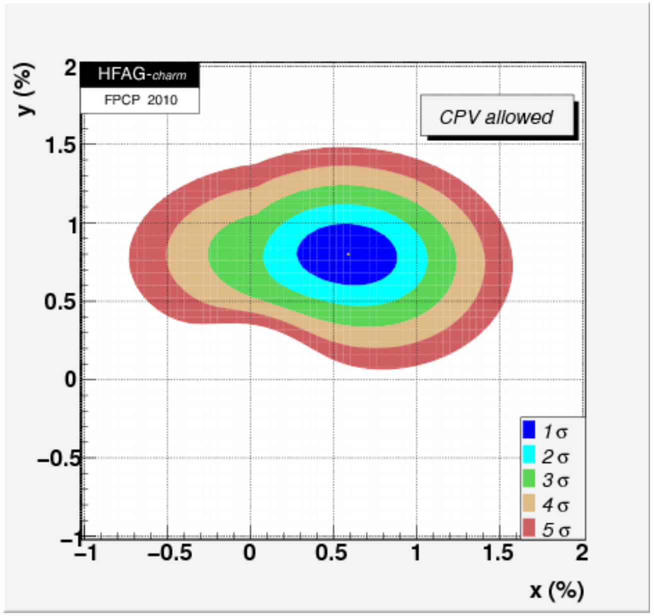


THE UNIVERSITY OF WARWICK
Tim Gershon
Discrete symmetries at LHC & beyond

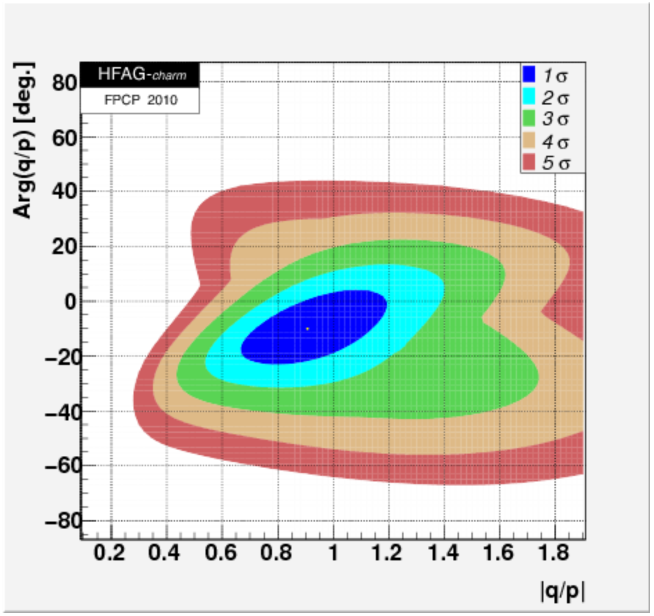
Search for CP violation in charm

	K^0	D^0	B^0	B_s	Charged mesons	Baryons	Charged leptons
CPV in mixing	✔	✘	✘	✘	Not applicable		
CPV in mixing/decay interference	✔	✘	✔	✘			
CPV in decay	✔	✘	✔	✘	✘	✘	✘

HFAG world average Including results from BABAR, Belle, CDF, CLEO(c), FOCUS



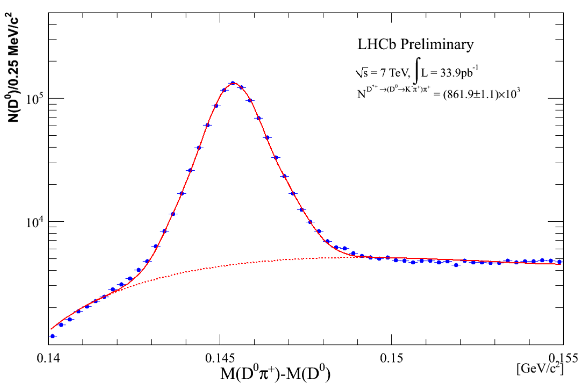
Inconsistent with no mixing point (0,0)



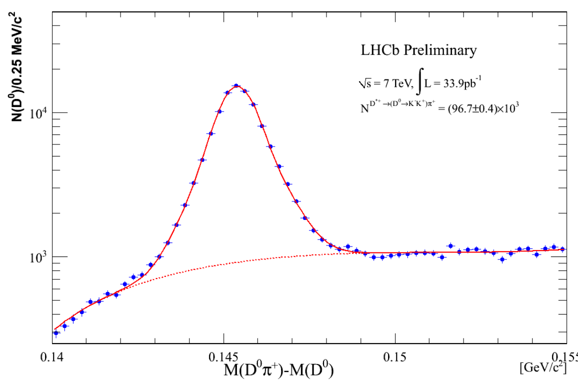
Consistent with no CP violation point (1,0)

Prospects for charm CP violation

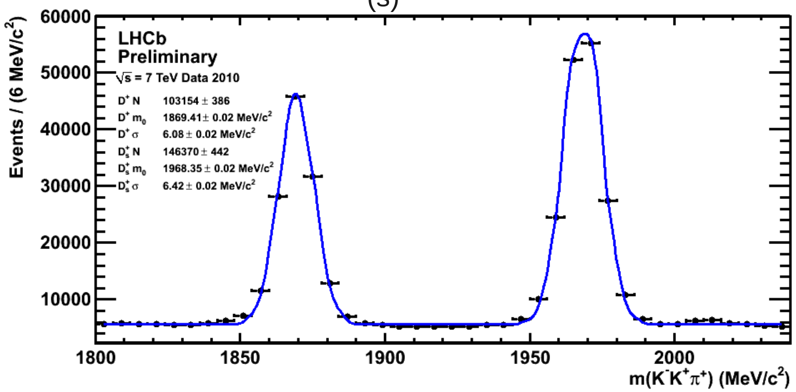
$D^{*\pm}\rightarrow D\pi^{\pm}$; $D\rightarrow K\pi$



$D^{*\pm}\rightarrow D\pi^{\pm}$; $D\rightarrow KK$



$D_{(s)}^{\pm}\rightarrow KK\pi^{\pm}$



Copious samples of charm already available

- e.g. 10^5 $D^{*\pm}\rightarrow D\pi^{\pm}$; $D\rightarrow KK$ events in 34/pb
- c.f. Belle: ~$3\text{x}10^5$ in 384/fb

Challenge is to control systematics to necessary level

- work in progress – expect world's best results in 2011

Tests of CPT symmetry at the LHC

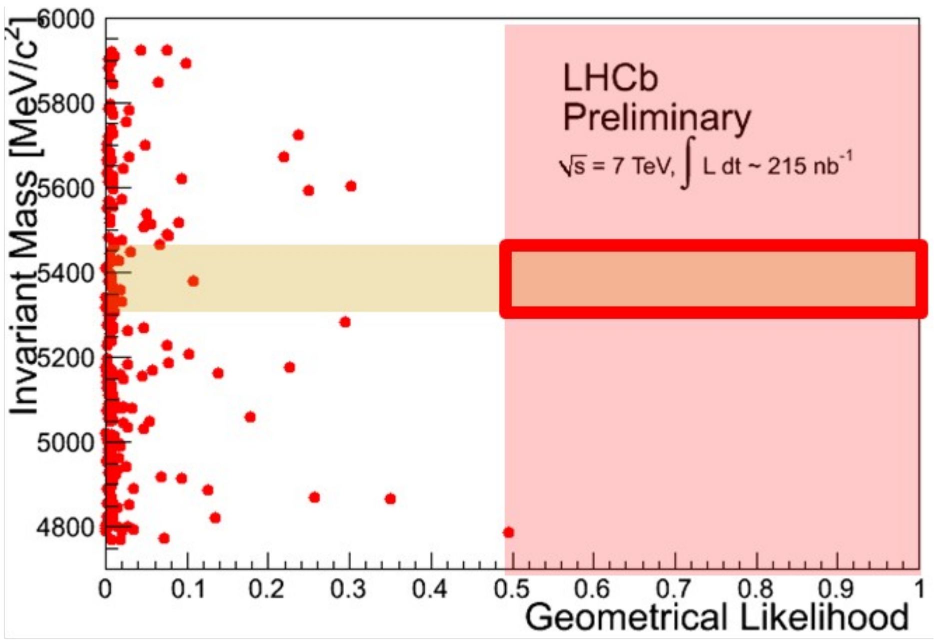
- The LHC B physics programme includes detailed studies of B_d, B_s and D^0 oscillations
- Main focus is on CP violation, but analyses can be extended to search for CPT violation
  - very few measurements exist in B_s and D^0 systems
  - no detailed sensitivity studies have been performed
- Can also test equivalence of particle-antiparticle mass and lifetimes for charged hadrons

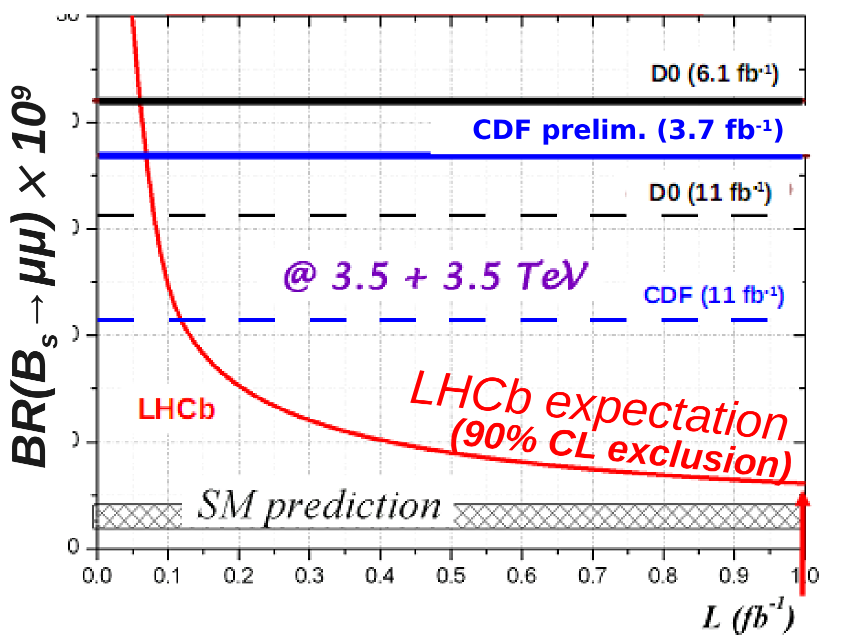
Global symmetries & rare decays

Global symmetries & rare decays

- Rare decays offer an excellent opportunity to test the accidental global symmetries of the Standard Model
- For example, lepton universality is affected by models with extended Higgs sectors
- Golden modes: $B_s \to \mu^+\mu^-$, $B \to K^*\mu^+\mu^-$

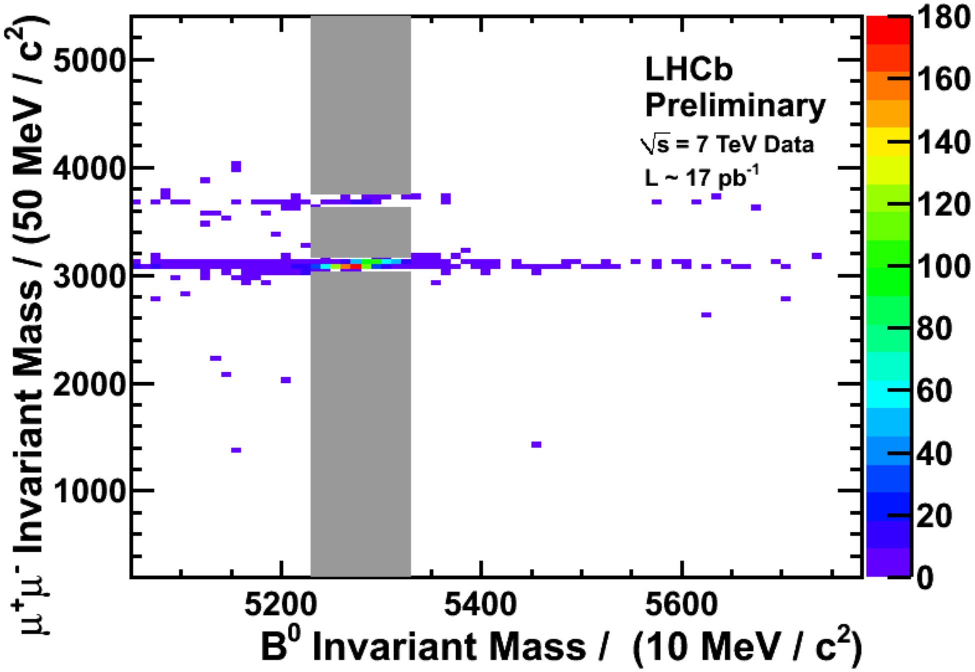
Prospects for $B_s \to \mu^+\mu^-$

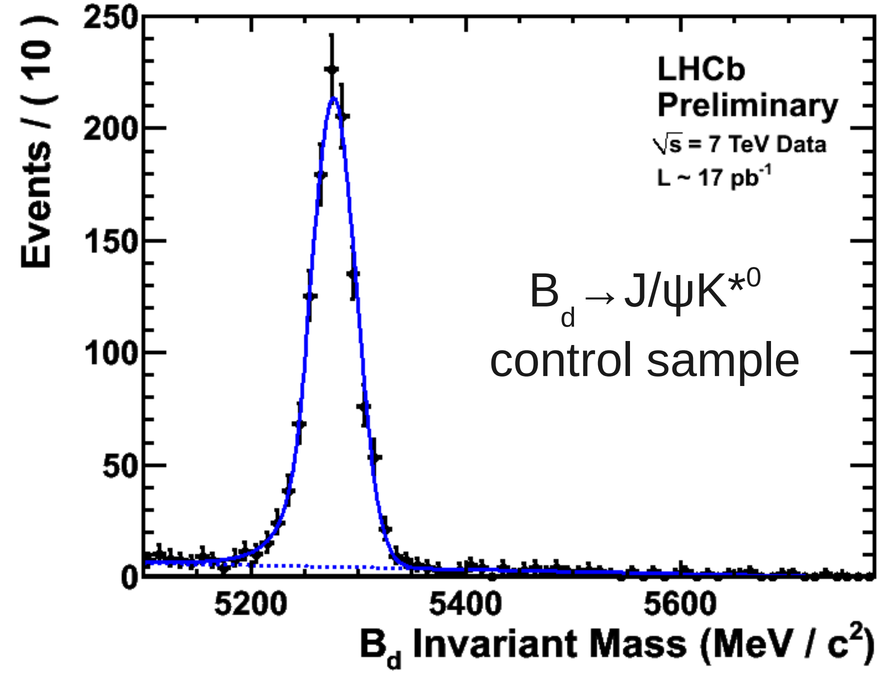




- Signal characterised by invariant mass and geometrical likelihood
- Background levels as expected in early data
- Expect stiff competition from ATLAS and CMS
  - sensitivity depends on $\mathscr{L}_{int}$, η range, trigger, mass resolution, etc.
  - 2011 data will allow to push limits down towards SM level

Prospects for $B \to K^*\mu^+\mu^-$

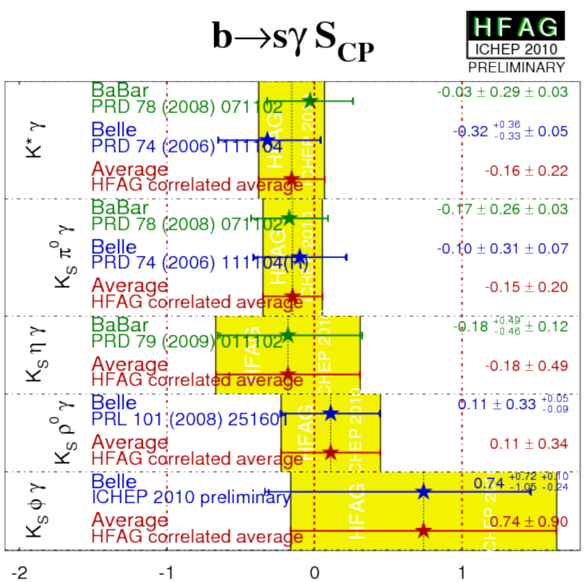




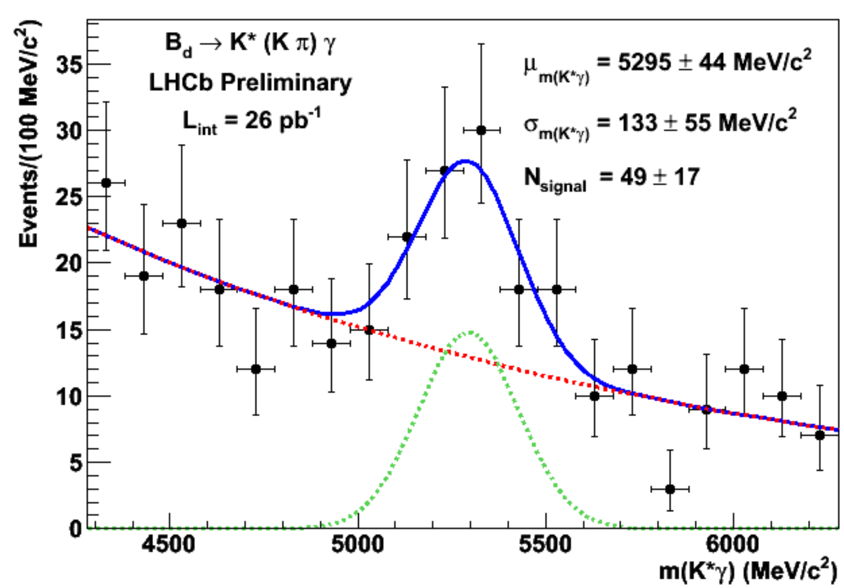
- Signal region blinded, but background levels low as expected
- Expect world's best measurement of $B \to K^*\mu^+\mu^-$ in 2011
  - Initial objective is to measure A_{FB} in bins of q^2
  - Large data sample will enable analyses of additional kinematic variables and heighten new physics sensitivity

Prospects for $B_s \to \varphi\gamma$

- Time-dependent asymmetries in $b \to s\gamma$ transitions act as a photon polarimeter
  - probe the V–A structure of the weak interaction
- B factories have studied several B_d channels
  - but $B_s \to \varphi\gamma$ is the golden mode for this measurement



$B_d \to K^*\gamma \to (K^+\pi^-)\gamma$ in 26/pb



Future projects

LHCb upgrade

- Main limitation of existing LHCb detector is the level 0 (hardware) trigger
- Need flexible (software) trigger to benefit from $\mathscr{L}$ above $10^{32}/cm^2/s$
  - higher $\mathscr{L}$ necessitates electronics and detector upgrades
- Enable full physics programme of LHCb as a general purpose detector in the forward region
  - unique discovery potential (not only flavour physics)
  - if NP is discovered in initial phase of LHC operation: characterisation of the Lagrangian
  - else: ultra-precise searches for (e.g.) non-standard CP violation

Next generation B factories

- LHCb has great potential in many – but not all – sectors
- Two important examples only accessible in e^+e^- collisions
  - $B^+ \rightarrow \tau\nu$, $\mu\nu$, $e\nu$ & rare τ decays (except $\tau \rightarrow 3\mu$)
- Two next generation experiments proposed
  - Belle2 – upgrade of Belle, approved in Japan, commissioning starts 2014
  - SuperB – new Italy-based project, reusing BaBar/PEP-II hardware, awaiting approval
- The two designs share much in common
  - One difference: potential for beam polarisation in SuperB

KEKB upgrade plans

Strategies for increasing luminosity

Beam-beam parameter

Lorentz factor

Beam current

$$\boxed{L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)}$$

Lumi. reduction factor (crossing angle)&
Tune shift reduction factor (hour glass effect)
0.8 - 1
(short bunch)

Classical electron radius

Beam size ratio@IP
1 - 2 % (flat beam)

Vertical beta function@IP

(1) Smaller β_y^*
(2) Increase beam currents
(3) Increase ξ_y

"Nano-Beam" scheme

Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB

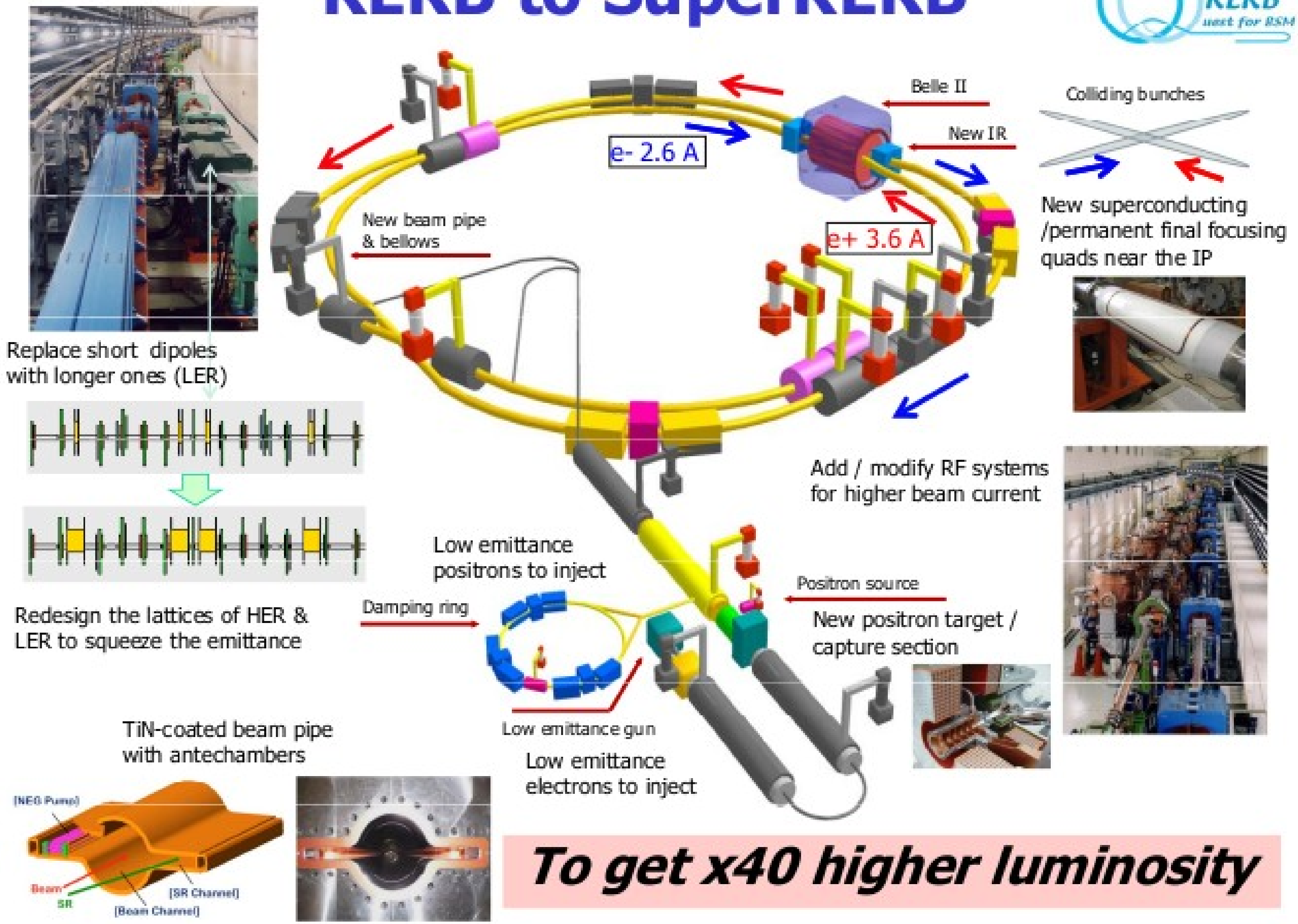
Machine design parameters

parameters		KEKB LER	KEKB HER	SuperKEKB LER	SuperKEKB HER	units
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	5.0	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.31	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0886	0.0830	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		$cm^{-2}s^{-1}$

- **Small beam size & high current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of LER short lifetime

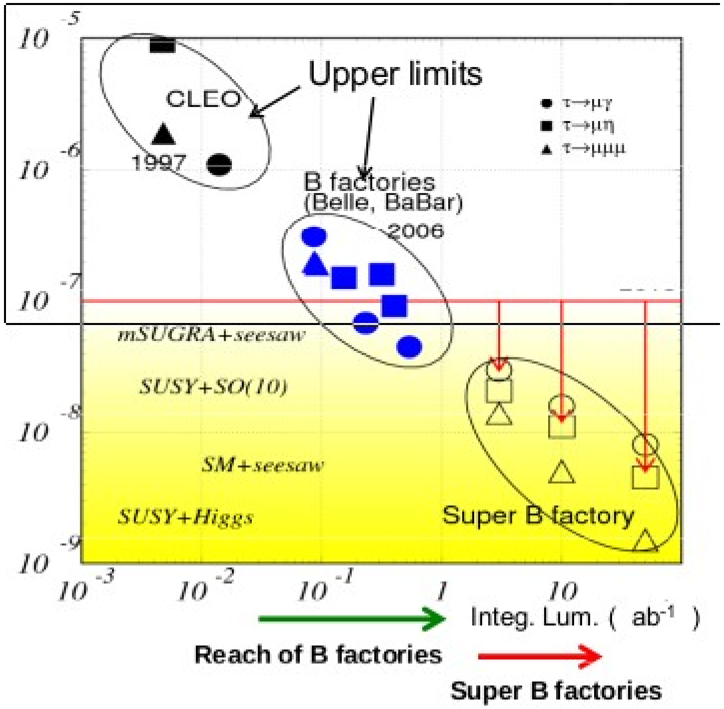
M. Iwasaki, ICHEP2010

KEKB to SuperKEKB



τ physics at e^+e^- Super B factories

- Search for lepton flavour violation (complementary to $\mu \to e\gamma$ at MEG, etc.)
- Search for CP violation: prominent channels: $\tau \to K^+\pi^0\nu$, $\tau \to K_S\pi^+\nu$
- Tests of CPT symmetry



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CPV in decay	✔	✘	✔	✘	✘	✘	✘

Summary

- Exciting times for CP violation studies at the LHC
- LHCb has excellent potential for major discoveries in many sectors of flavour physics
  - if large non-standard effects are present, 2011 will be a spectacular year!
- Expect competition from ATLAS & CMS in modes with muons, particularly $B_s \to \mu^+\mu^-$
  - (also potential for CP violation studies in the top sector)
- Planned future experiments will ensure progress in understanding flavour physics and discrete symmetries throughout the LHC era