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CP Violation @ LHC
Results and Prospects

Tobias Brambach on behalf of the LHCb Collaboration

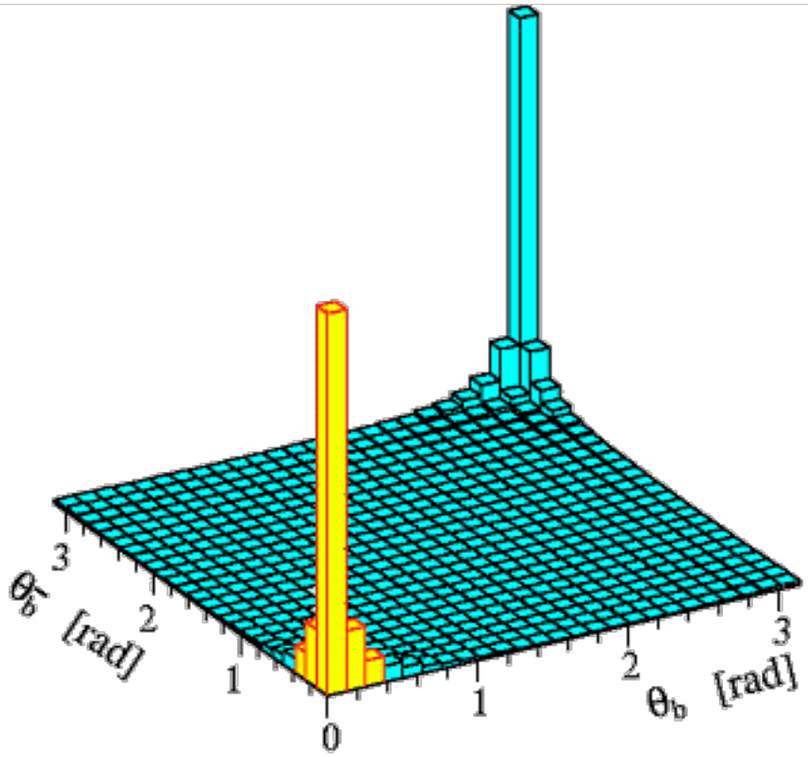
LHCb physics goals

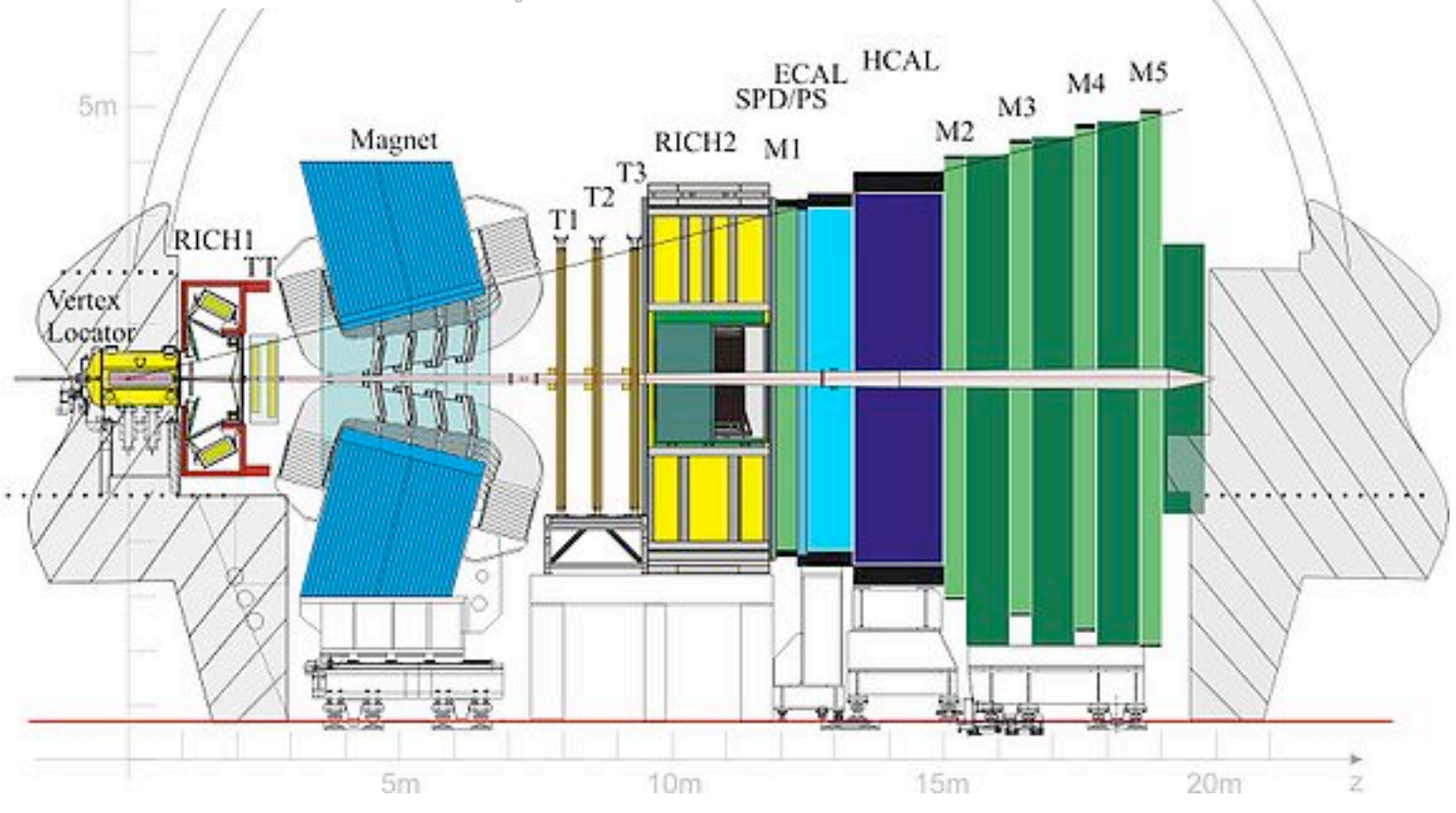
precision tests of SM and search for new physics in...

- rare decays
  (talk by Christian Elsasser)
- CP violation in
  - loop mediated processes
  - B_d and B_s decays
  - decays of D mesons
- electroweak sector

The LHCb detector

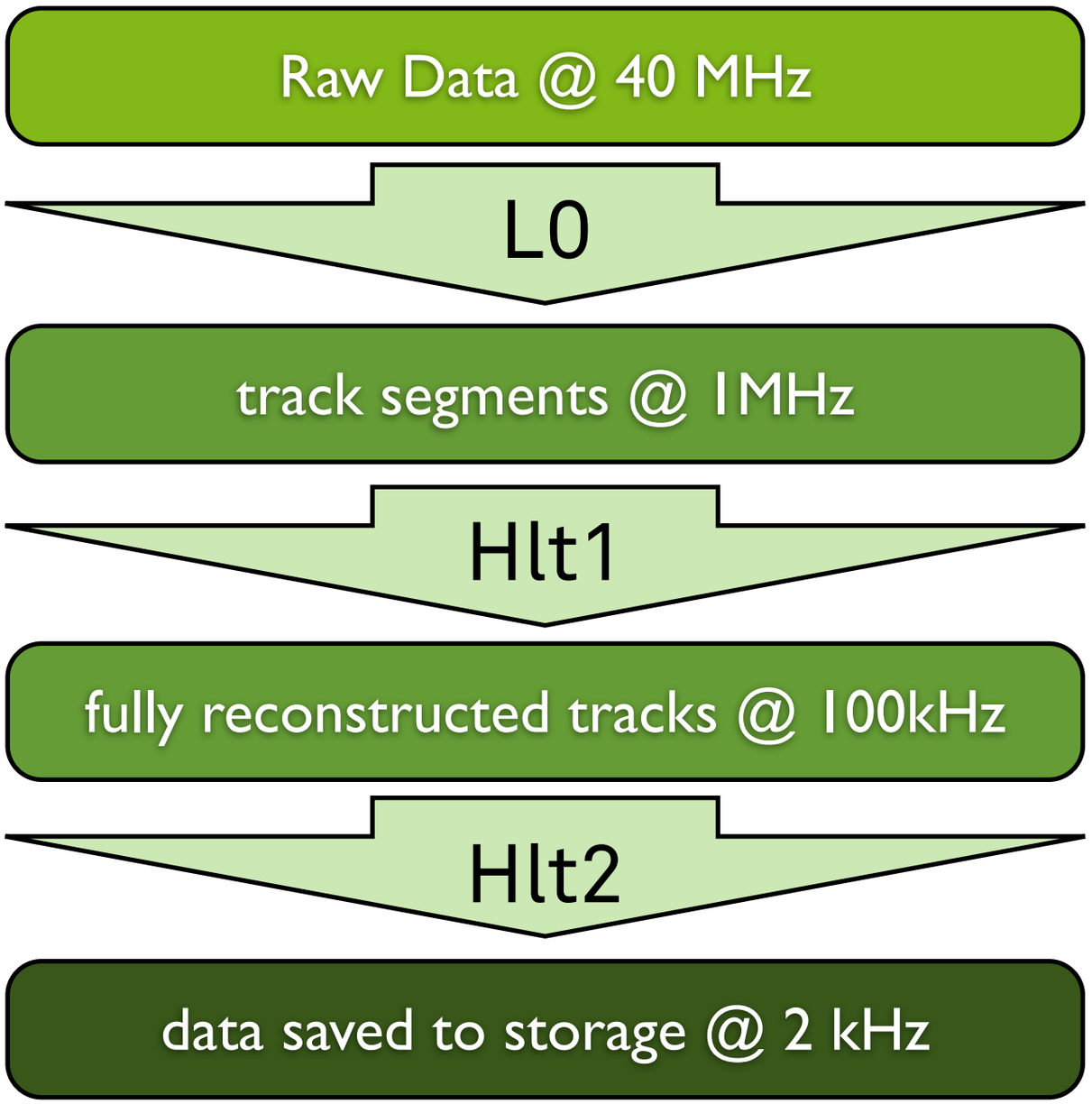
- One arm forward spectrometer, fully instrumented in forward direction
- $1.9 < \eta < 4.9$
- Very good lifetime resolution (~50 fs)
  - long flight length (boost)
  - strong spacial resolution
- Strong particle identification using two RICH detectors, scintillator pad, preshower detector and muon system
- tracking stations before and after magnet
- one quarter of B mesons produced in LHCb interaction point are within LHCb acceptance



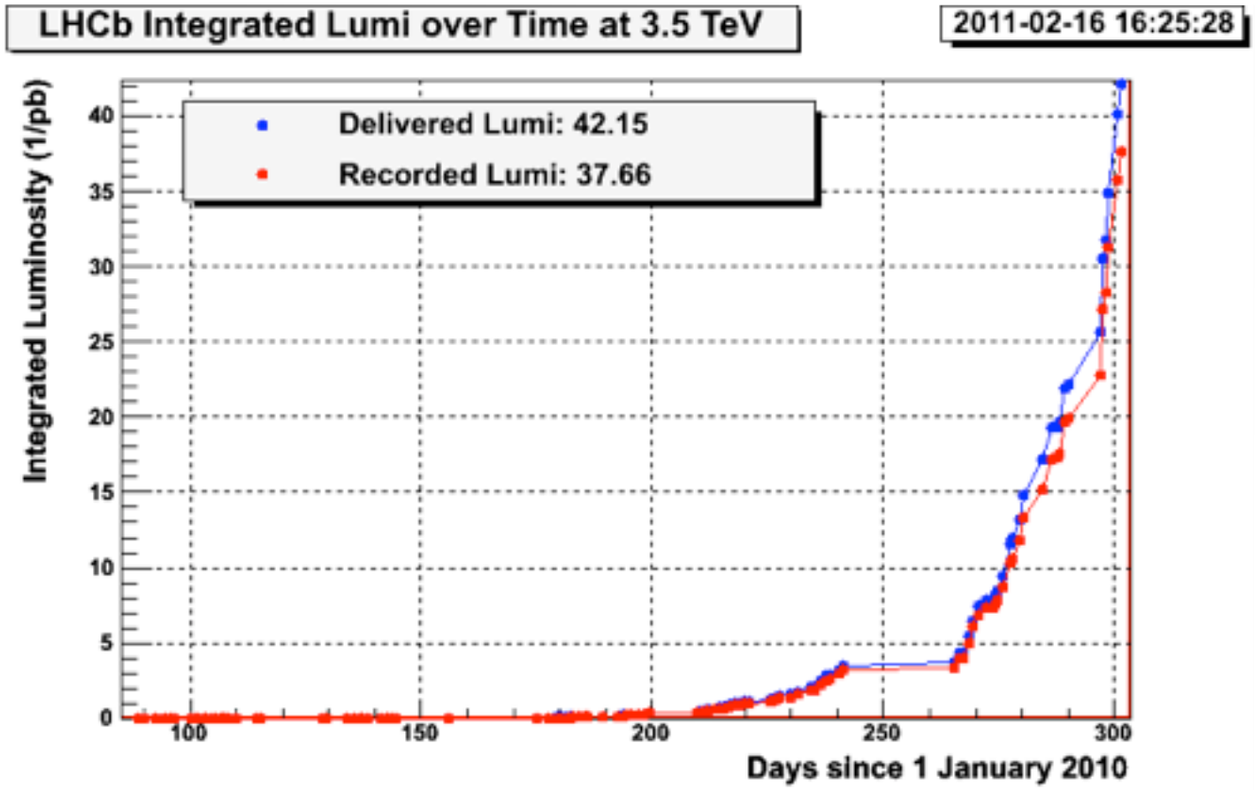


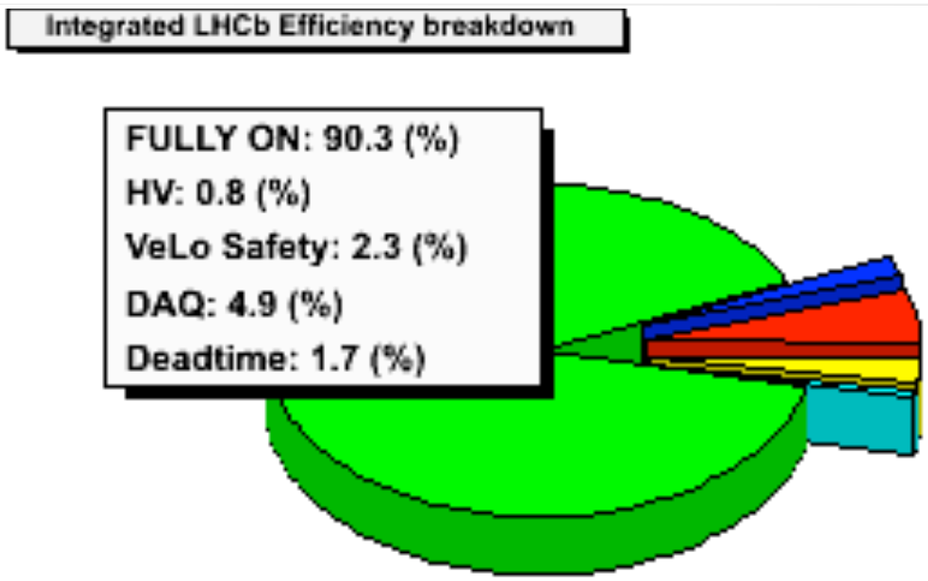
LHCb triggers

- 3 trigger levels
  - one Hardware
  - two software
- all tracks available to Hlt2
- data reduction by factor of 20k
- stripping after Hlt2 – further reduction of data (possible reprocessing)
- triggers not yet in nominal setup because of lower interaction rate from LHC



2010 detector performance

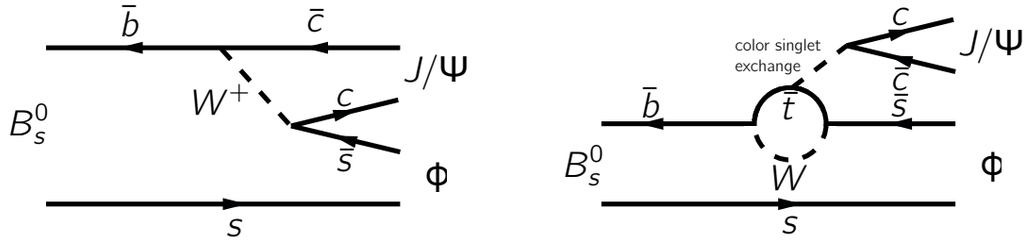


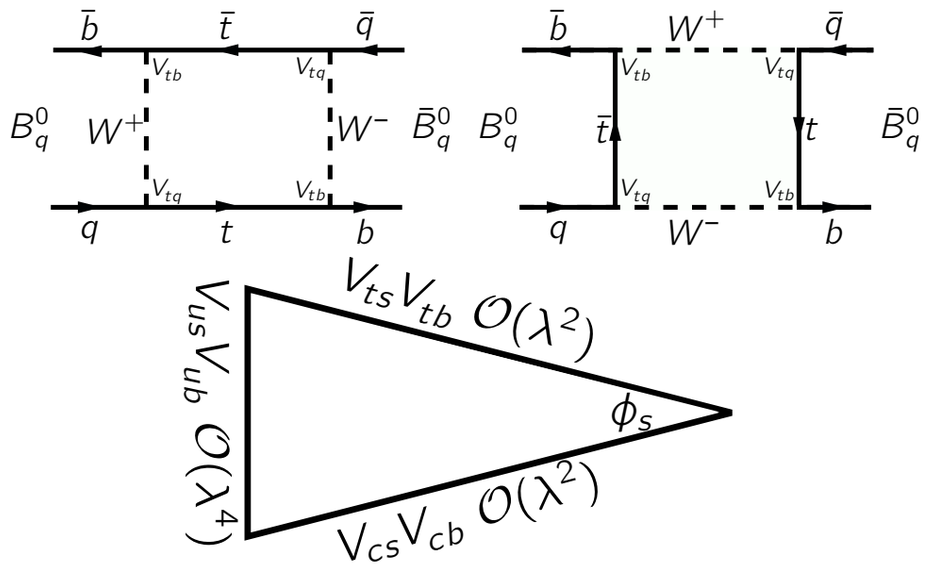


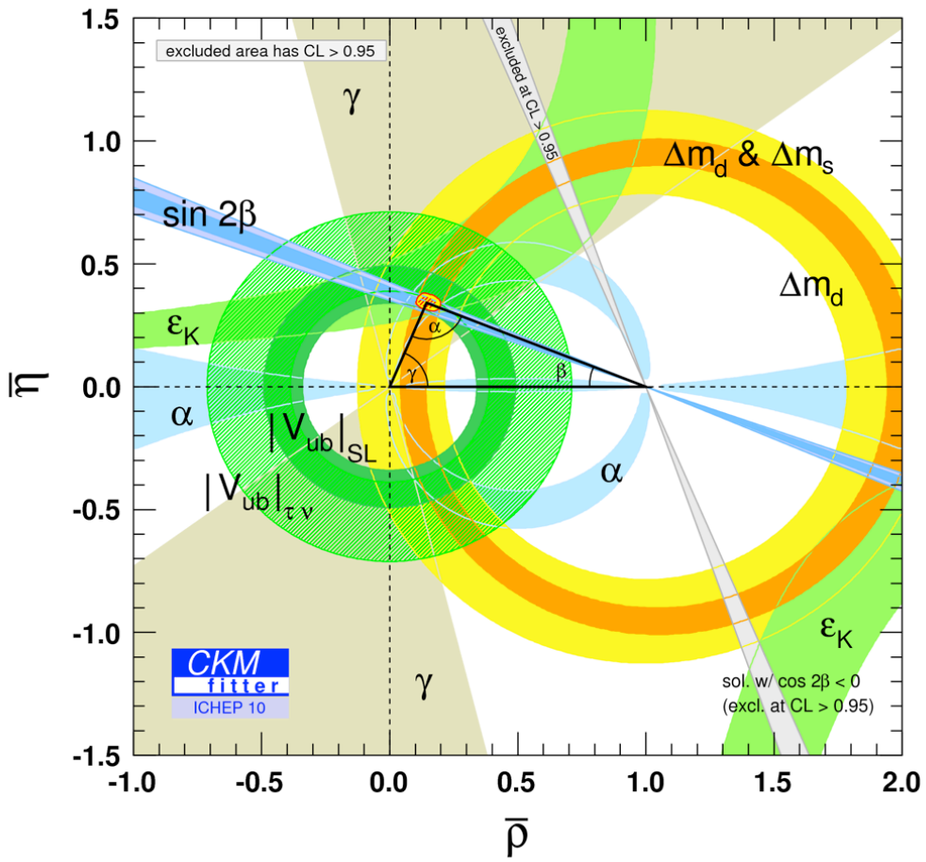
- LHC performance increasing rapidly through the year
- LHCb was running >90% of stable beam time
- higher pile up than expected → more Bs
- collected a total of ~37 pb^{-1} @ $\sqrt{s}$ = 7 TeV
- 1 fb^{-1} expected for 2011
  - 5x smaller statistical errors

What are we looking for?

- search for constraints on CKM angle γ
- perform time dependent analysis for sin 2β

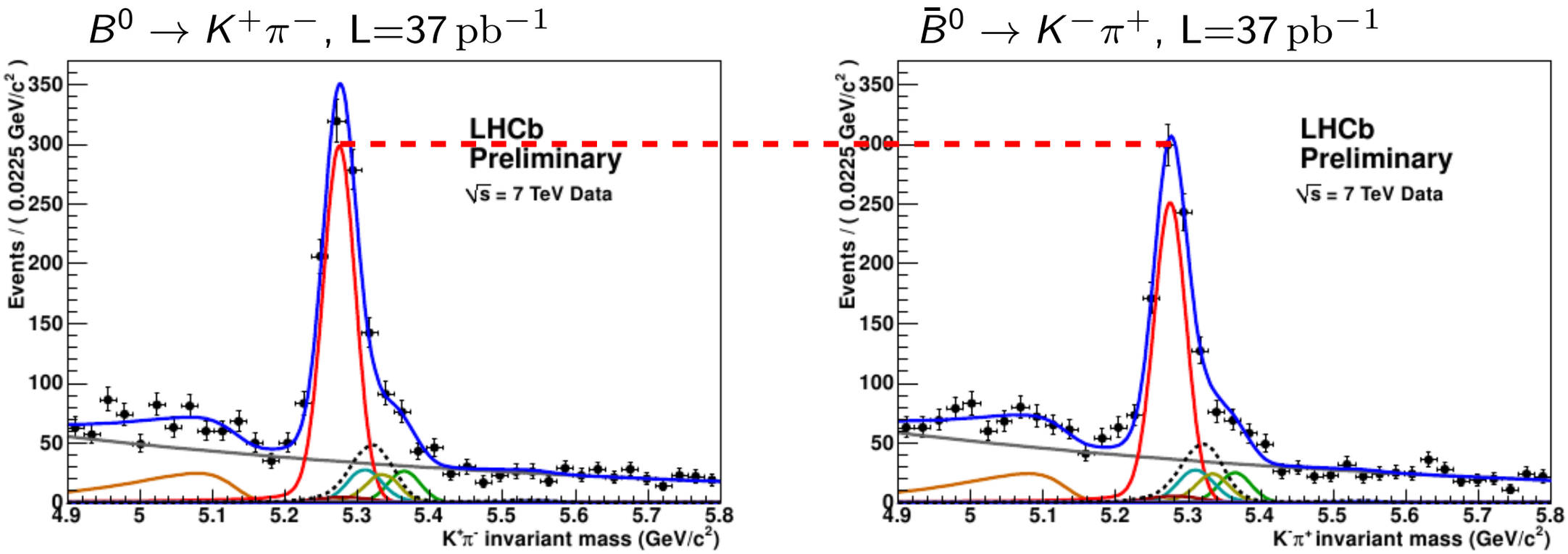






- new physics may be induced through loop and box structures
- golden mode for ϕ_s at LHCb: $B_s \rightarrow J/\psi\ \phi$

A first sign of CPV @ LHCb

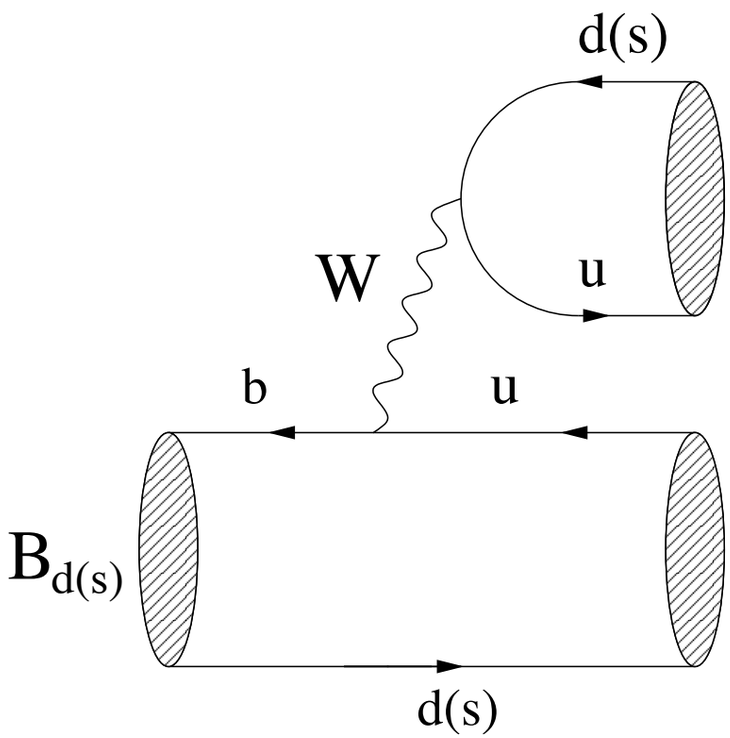


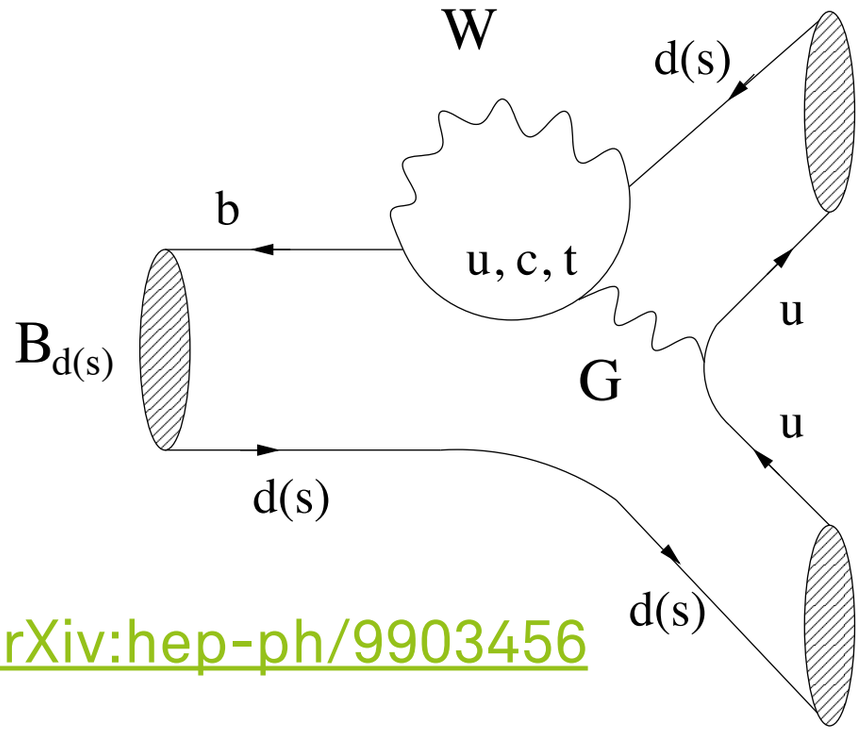
	LHCb	world average
$A_{CP}(B^0 \to K^+\pi^-)$	$-0.077 \pm 0.033_{stat.} \pm 0.007_{syst.}$	-0.098 ± 0.012
$A_{CP}(B_s \to \pi^+K^-)$	$0.15 \pm 0.19_{stat.} \pm 0.02_{syst.}$	0.39 ± 0.17

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

LHCb CONF 2011-011

Hadronic modes for γ





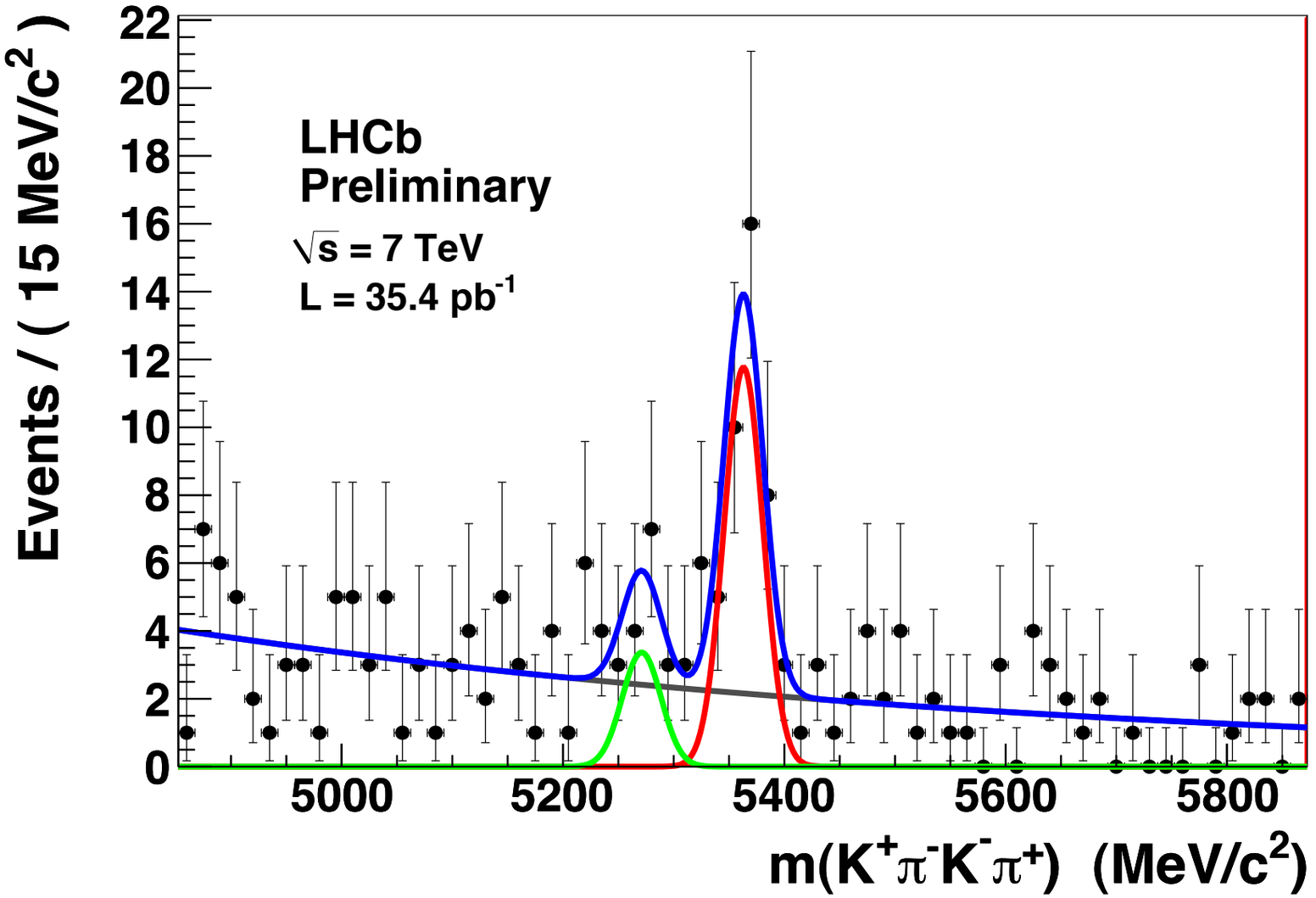
arXiv:hep-ph/9903456

- strategy for extraction of gamma relying on interference between tree and penguin diagrams
- use $B_d \to \pi K$, $B_d \to \pi\pi$, $B_s \to \pi K$, $B_s \to KK$, $\Lambda_b \to p\pi$, $\Lambda_b \to pK$ modes to extract γ

First observation of $B_s \to K^* K^*$

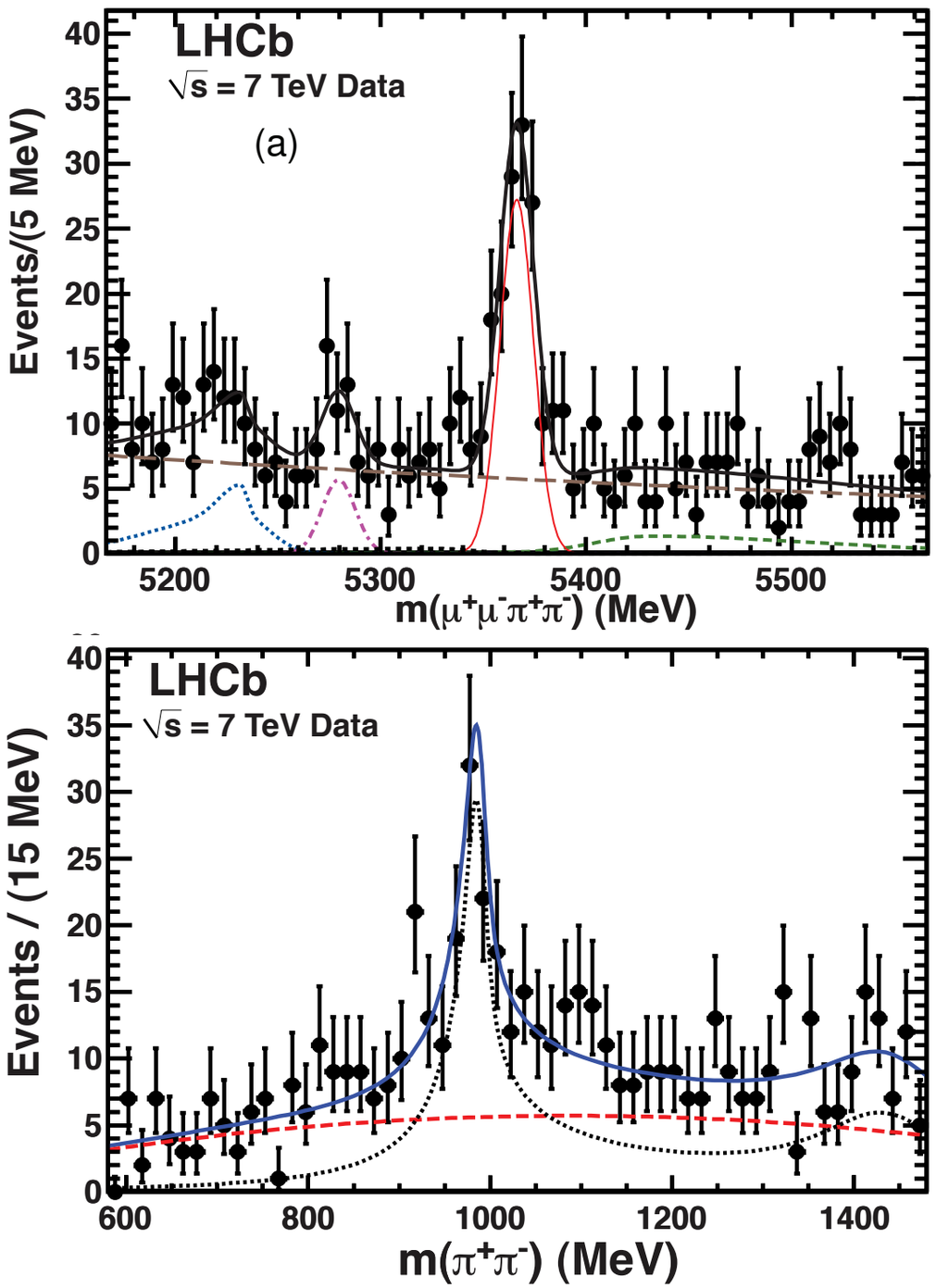
- 7.4σ significance
- 35.4 pb^{-1}
- sensitivity to NP in mixing box and penguin diagram
- no measurement of CPV, yet

$$\mathcal{B}(B_s \to K^* \bar{K}^*) = (1.95 \pm 0.47_{\text{stat.}} \pm 0.66_{\text{syst.}} \pm 0.29_{f_d/f_s}) \cdot 10^{-5}$$



$B_s \to J/\psi\, f_0(980)$– first observation

- measurement of the branching ratio of the two interfering resonances $f_0(980)$ and $f_0(1370)$
- CP odd final state, therefore possible measurement of ϕ_S without angular analysis
- ratio to $J/\psi\, \phi(K^+K^-)$ production
- $$R_{f_0/\phi} = \frac{\Gamma(B_s \to J/\psi\, f_0,\ f_0 \to \pi^+\pi^-)}{\Gamma(B_s \to J/\psi\, \phi,\ \phi \to K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$
- R. Aaij et al. (LHCb Collaboration), Physics Letters B 698 (2011) pp. 115-122, arxiv:hep-ex/1102.2006

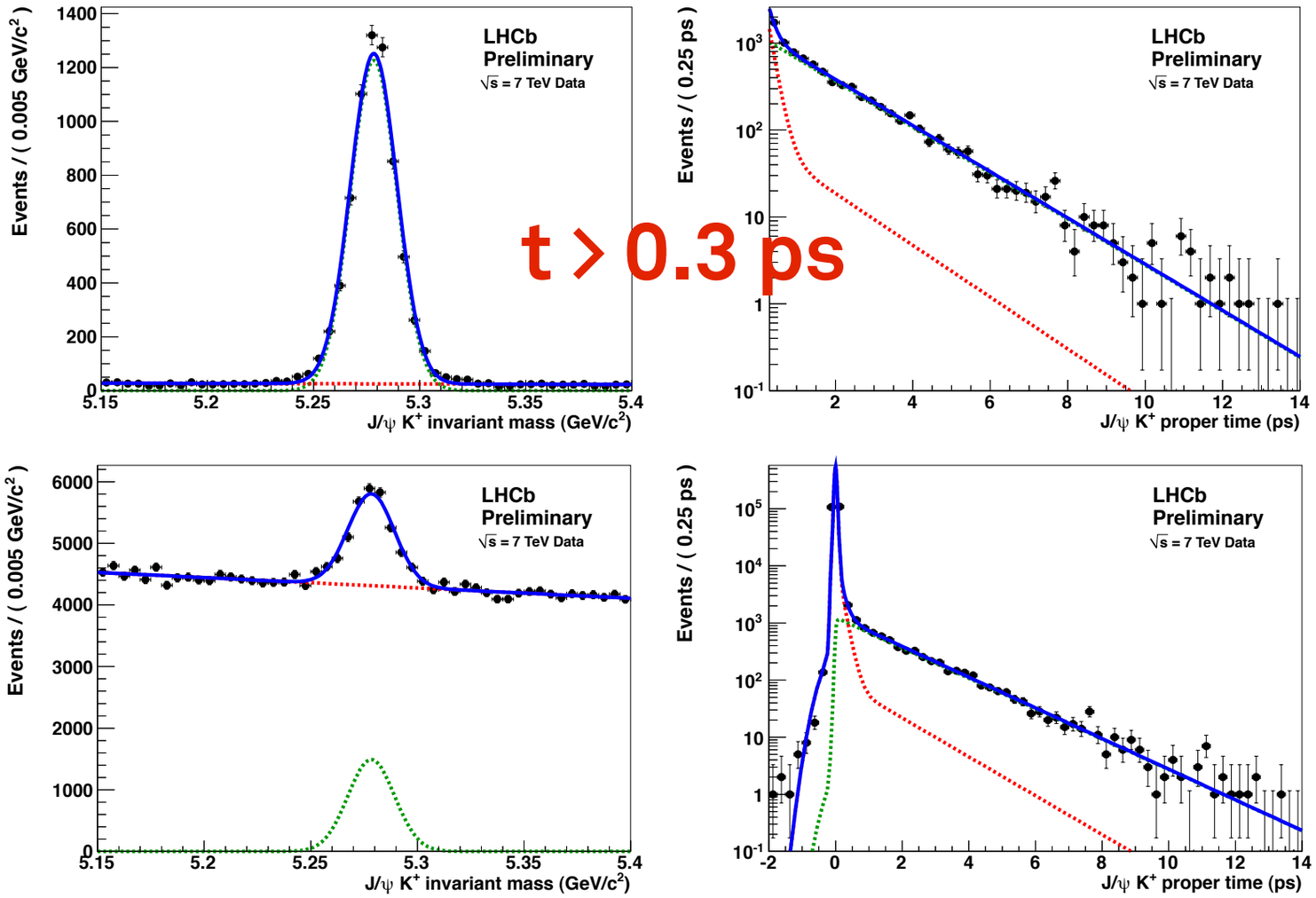


The quest for ϕ_S

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

Lifetimes

- lifetime measurement for B_u, B_d, B_s and Λ_b
- investigation of lifetime biases
  - propertime acceptance

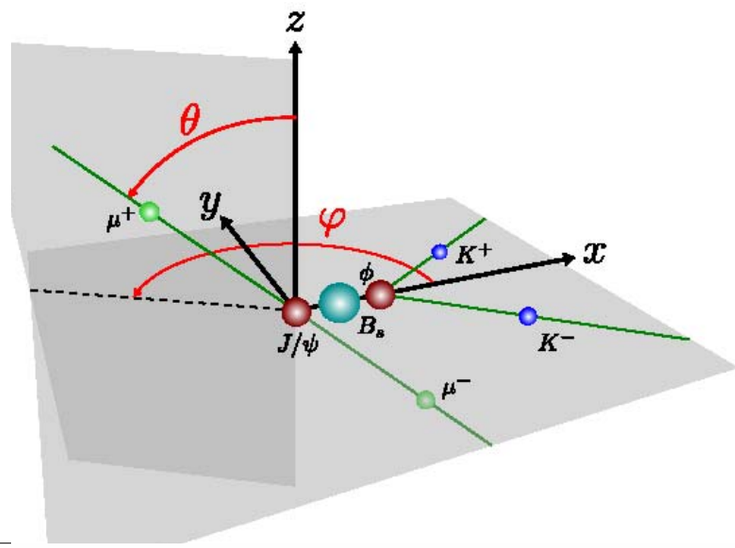


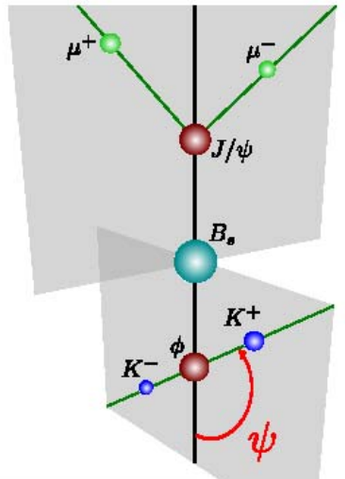
world average PDG 2010	
	$\tau(B^+)$ = 1.638 ± 0.011 ps
	$\tau(B^0)$ = 1.525 ± 0.009 ps
	$\tau(B_s)$ = 1.472 ± 0.025 ps
	$\tau(\Lambda_b)$ = 1.391 ± 0.038 ps

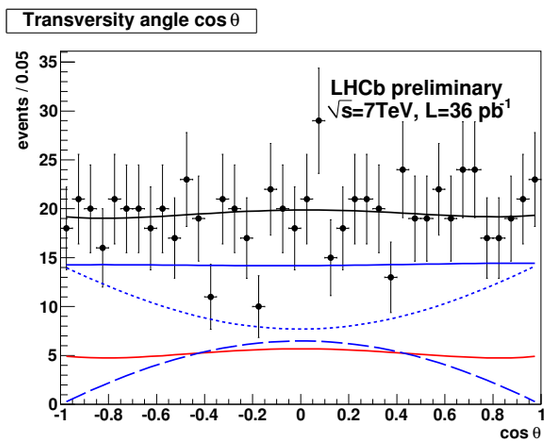
$$\tau(B^+ \to J/\psi K^+) = 1.689 \pm 0.022\ (\text{stat.}) \pm 0.047\ (\text{syst.})\ \text{ps}$$
$$\tau(B^0 \to J/\psi K^{*0}) = 1.512 \pm 0.032\ (\text{stat.}) \pm 0.042\ (\text{syst.})\ \text{ps}$$
$$\tau(B^0 \to J/\psi K^0_S) = 1.558 \pm 0.056\ (\text{stat.}) \pm 0.022\ (\text{syst.})\ \text{ps}$$
$$\tau^{\text{single}}(B^0_s \to J/\psi \phi) = 1.447 \pm 0.064\ (\text{stat.}) \pm 0.056\ (\text{syst.})\ \text{ps}$$
$$\tau(\Lambda_b \to J/\psi \Lambda) = 1.353 \pm 0.108\ (\text{stat.}) \pm 0.035\ (\text{syst.})\ \text{ps}$$

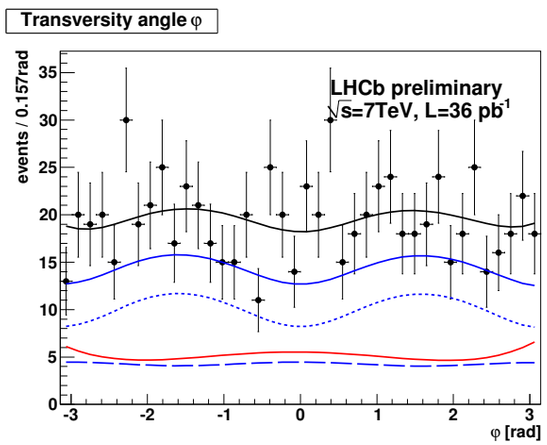
Measurement of ϕ_s

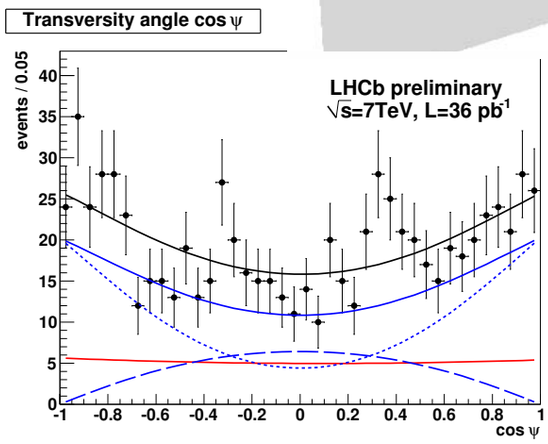
- final state of $B_s \to J/\psi\, \phi$ is no CP eigenstate
  - admixture of different CP eigenstates in P → VV decay
- there are different amplitudes belonging to different angular momenta
- use a four dimensional pdf in time and three transversity angles to extract ϕ_s and $\Delta\Gamma_s$



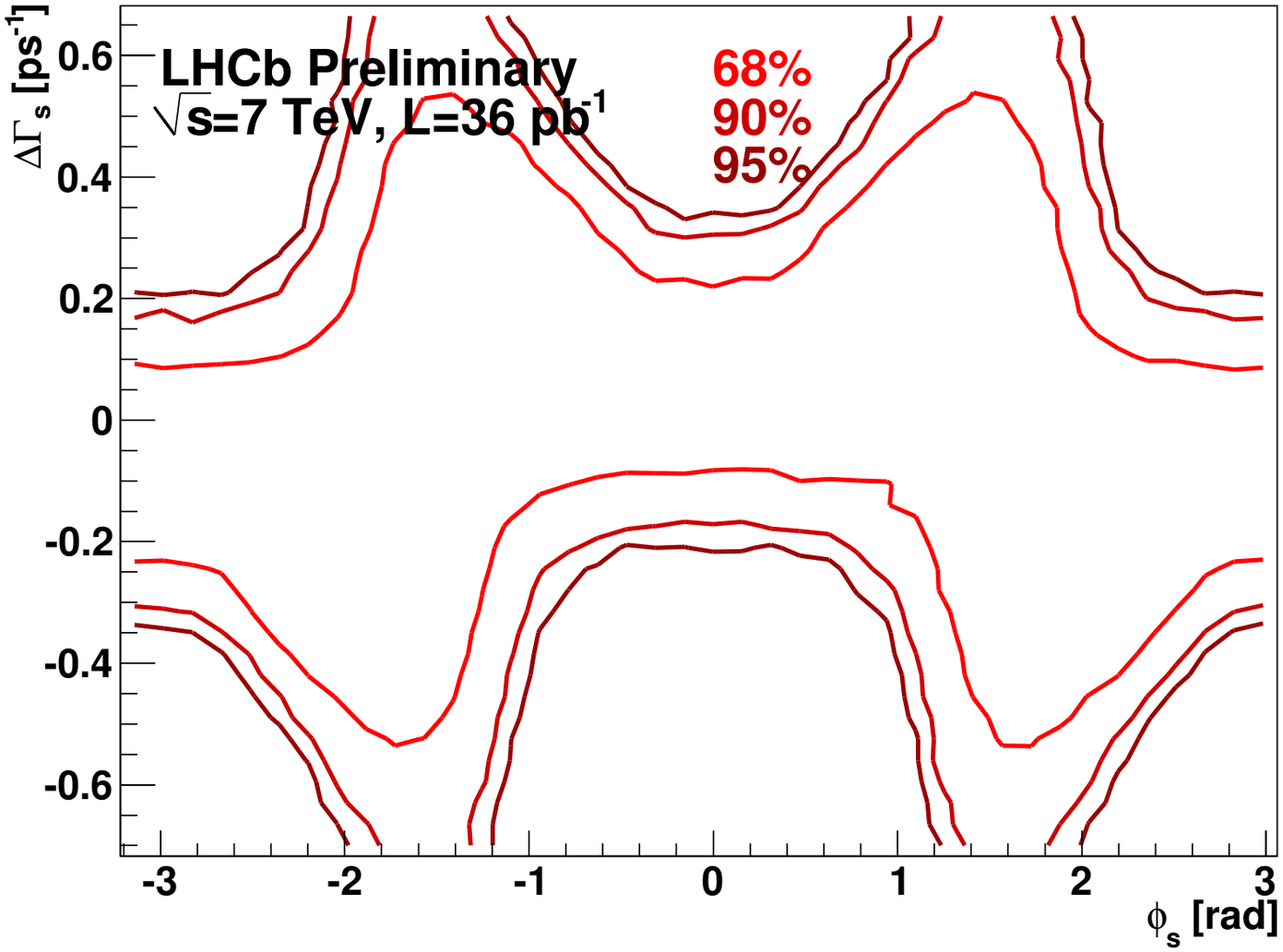






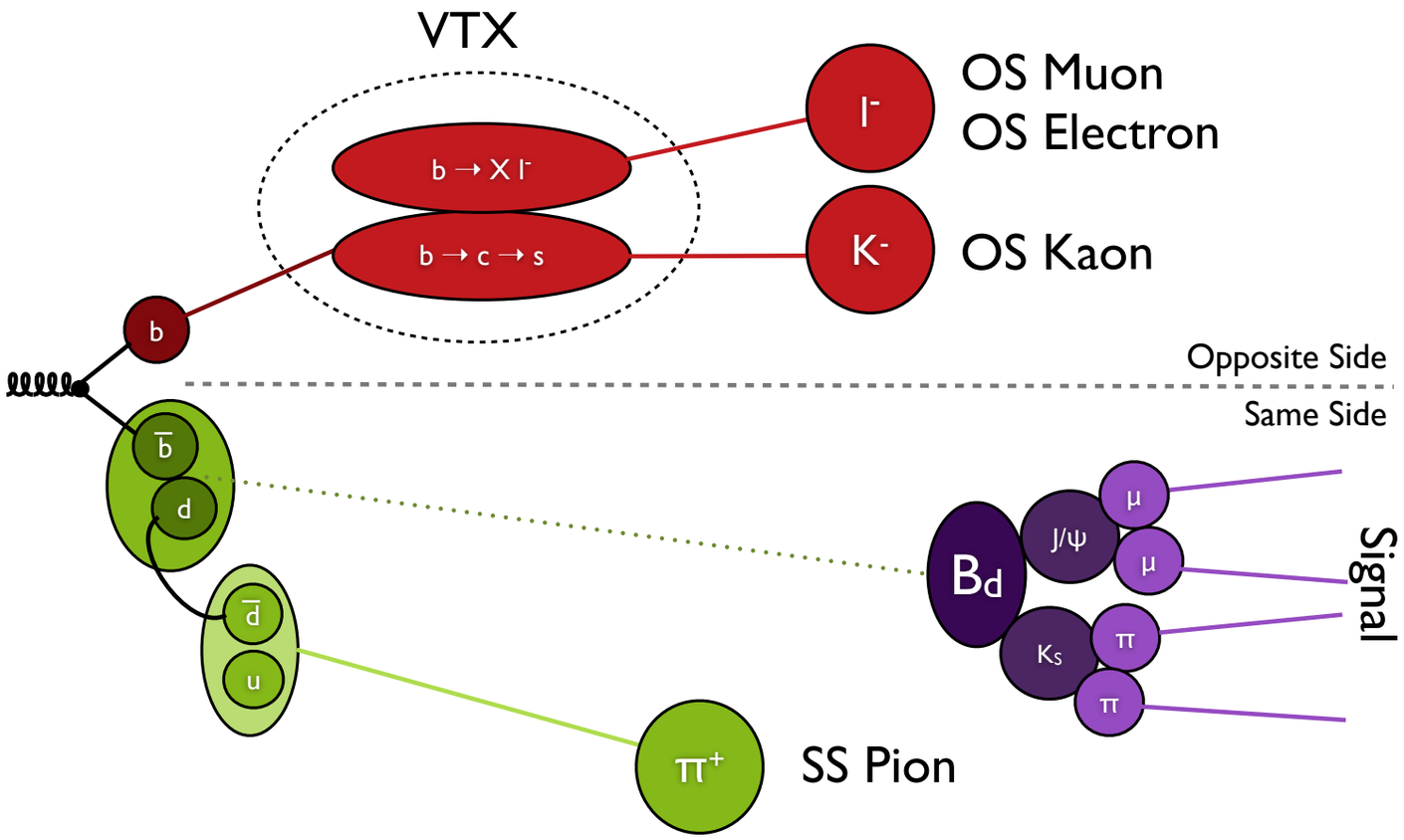


Untagged analysis

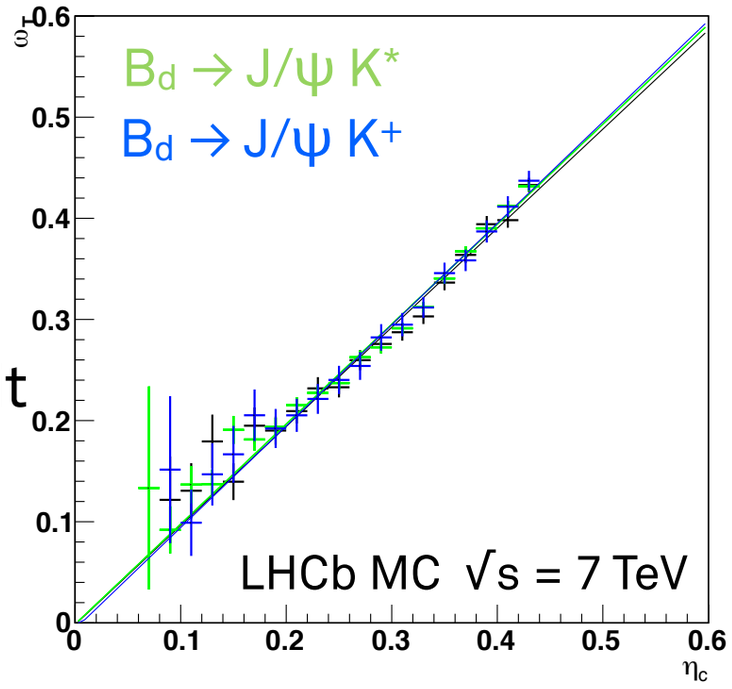


- no constraint on ϕ_S in untagged analysis
- tagging needed to reduce four-fold to two-fold ambiguity

Tagging calibration (1)



difference between predicted η and measured ω mistag probability on MC and fit of linear calibration function



- use neural nets, trained on MC, to extract tagging decision and mistag probability η
- calibrate mistag with linear function on high yield data samples with self tagging final states
- crosscheck calibration on other channels

Tagging calibration (2)

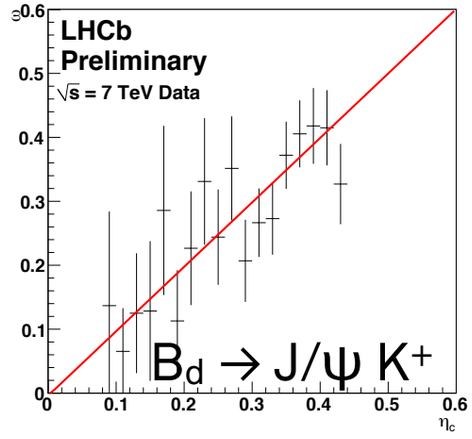
- fit of linear calibration function
  $\omega(\eta) = p_0 + p_1 (\eta - \langle\eta\rangle)$
  on data
- calculation of effective efficiencies εD^2

OS+SS-π	$\varepsilon_{\text{tag}}(\%)$	$\omega(\%)$	$\varepsilon_{\text{eff}}(\%)$
$B^0 \to D^{*-} \mu^+ \nu_\mu$	28.9 ± 0.2	34.2 ± 0.8	2.87 ± 0.32
$B^+ \to J/\psi K^+$	23.0 ± 0.5	33.9 ± 1.1	2.38 ± 0.33
$B^0 \to J/\psi K^{*0}$	26.1 ± 0.9	33.6 ± 5.1	2.82 ± 0.87

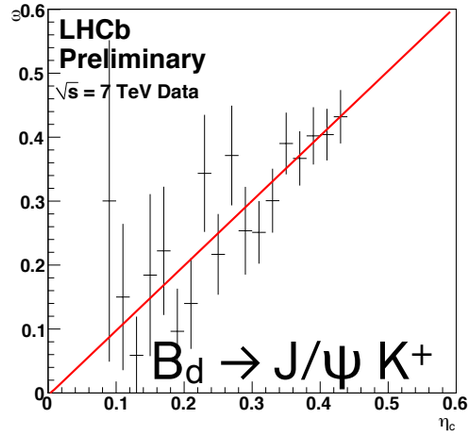
$$\varepsilon_{\text{tag}} = \frac{R+W}{R+W+U} \qquad \omega = \frac{W}{R+W}$$

$$\varepsilon_{\text{eff}} = \varepsilon_{\text{tag}} D^2 = \varepsilon_{\text{tag}}(1-2\omega)^2$$

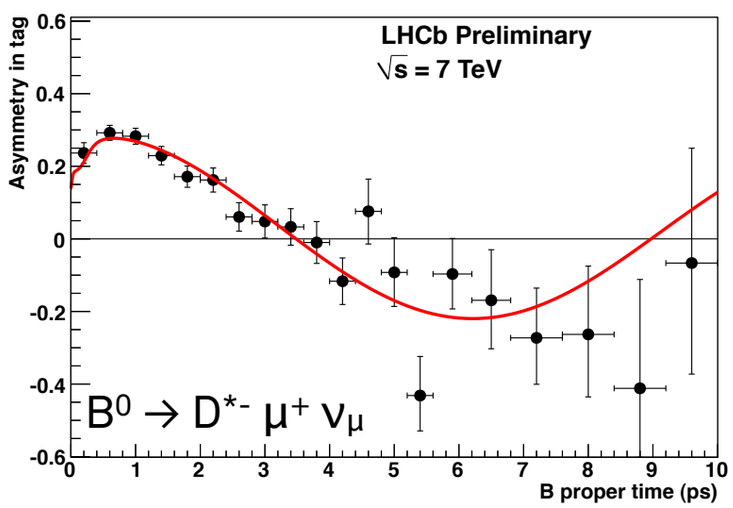
OS combination calibration

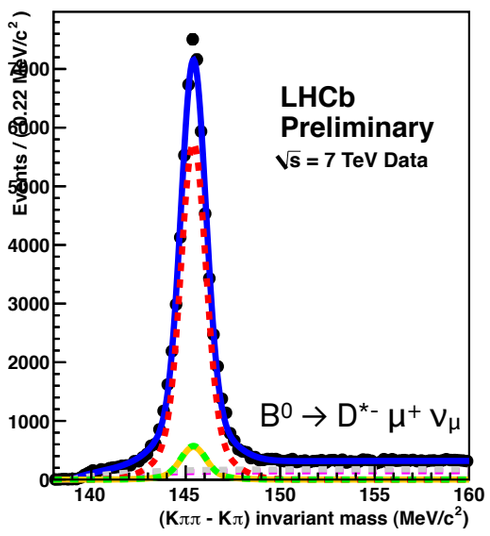


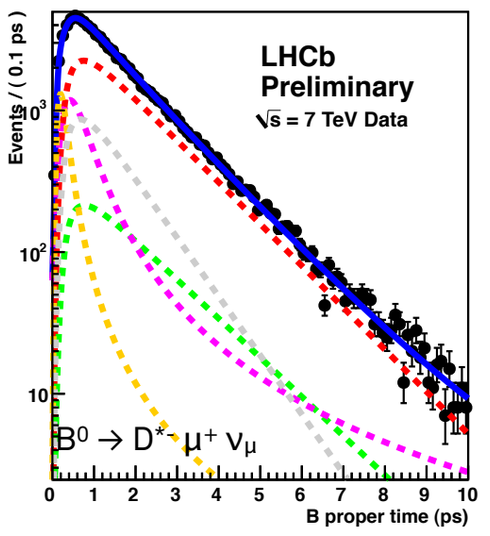
SSπ + OS combination calibration



Flavour Oscillation signal region



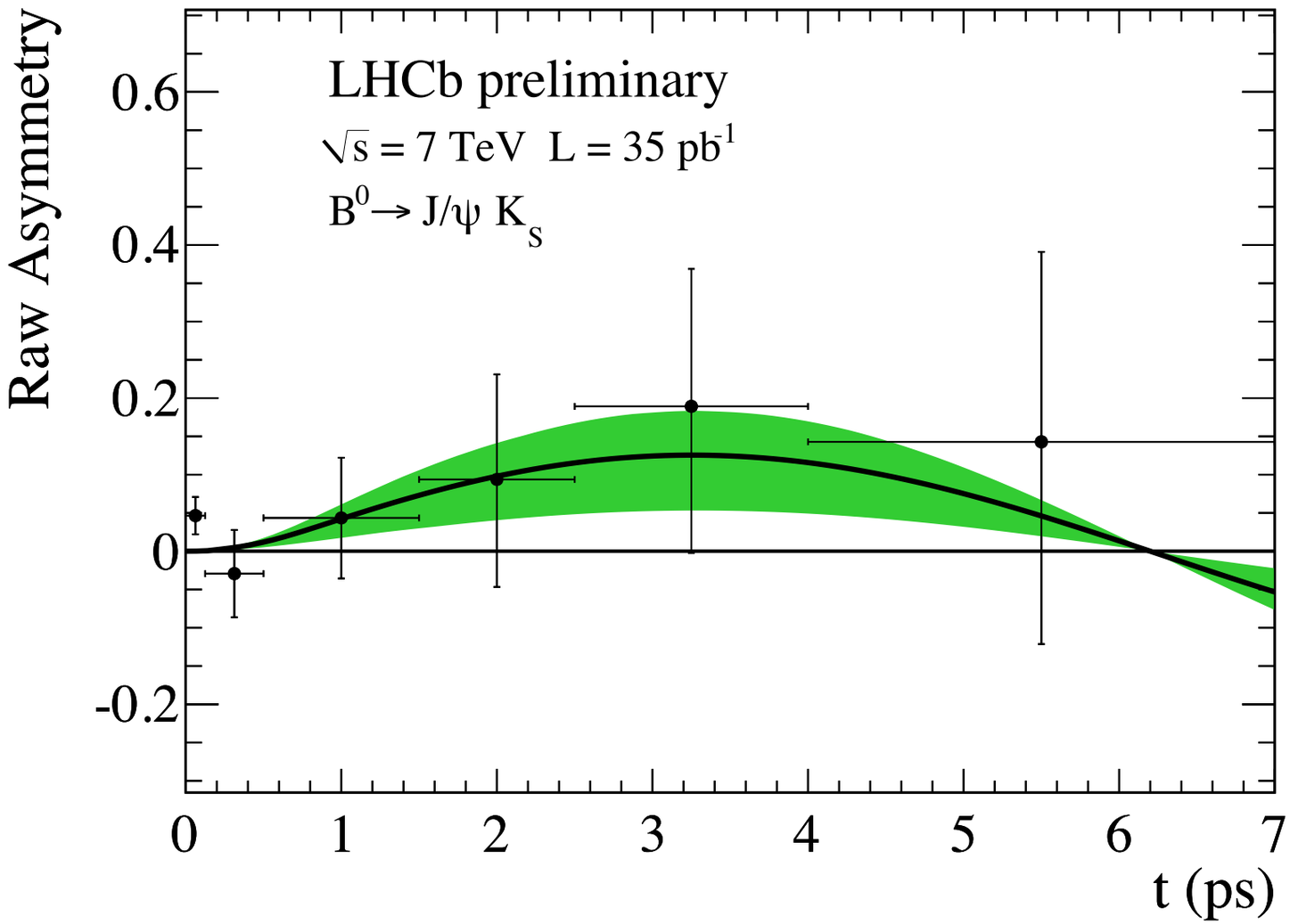




sin 2β from $B_d \to J/\psi K_S$

first time dependent measurement of CPV @ LHCb

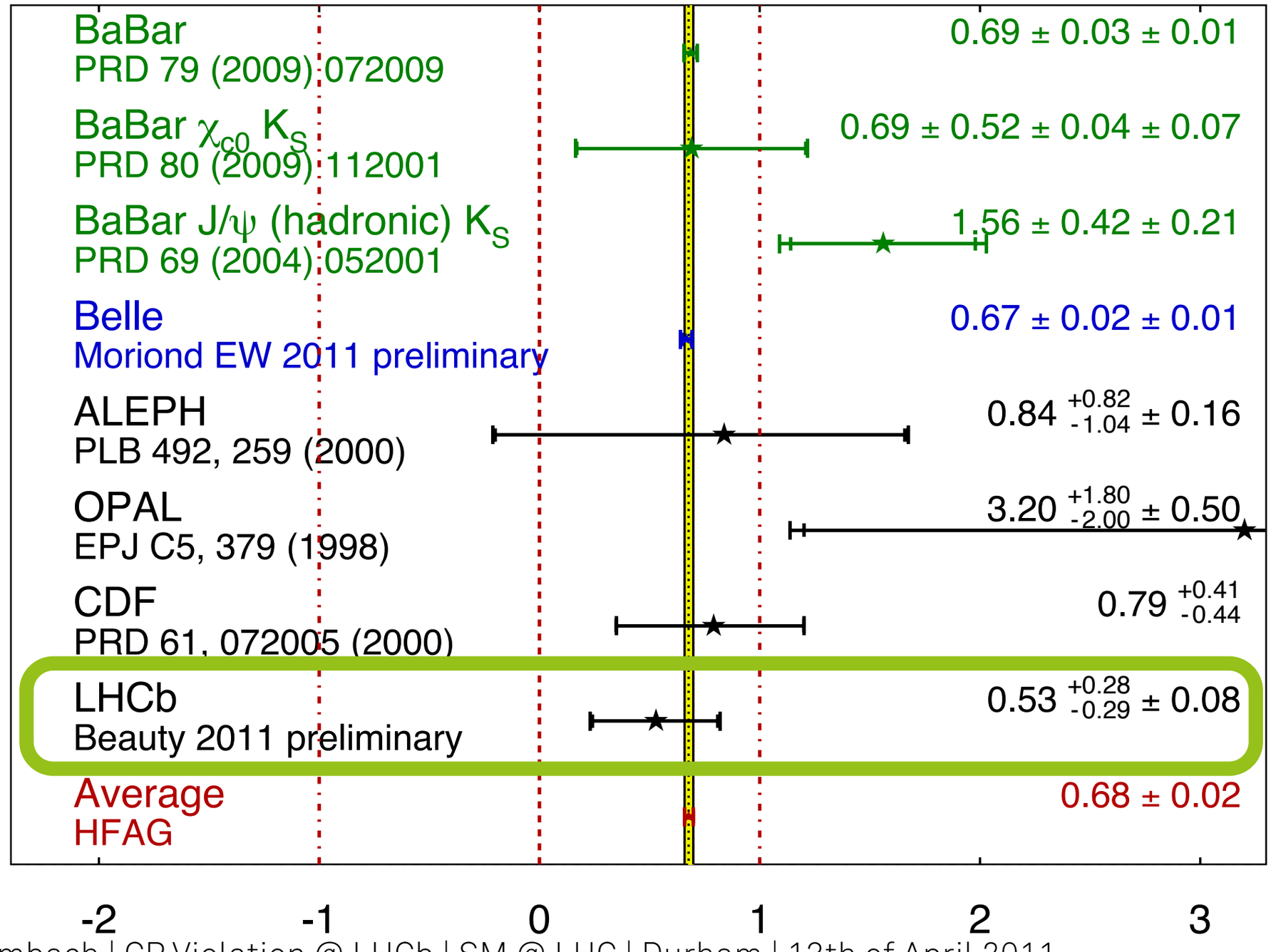
- first measurement of time dependent CP asymmetries @ LHCb
- best measurement of sin 2β at a hadron machine
- statistic uncertainty as expected
- systematic uncertainty will decrase in future
  - tagging calibration
  - production asymmetries



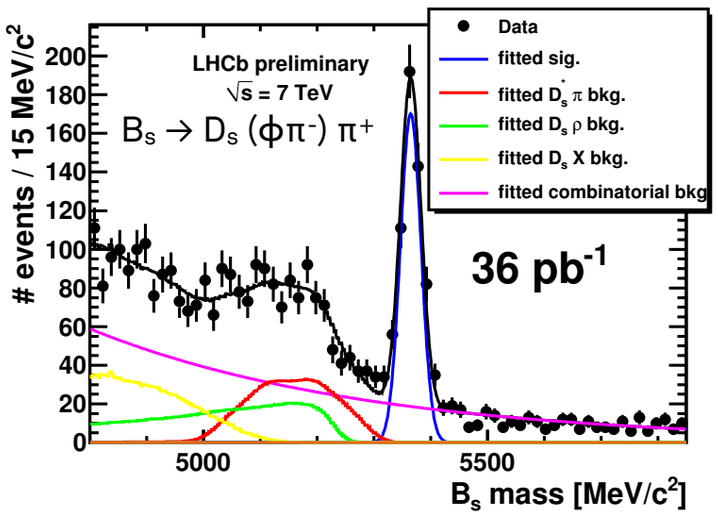
$$S_{J/\psi K_S^0} = 0.53^{+0.28}_{-0.29}(stat.) \pm 0.08(syst.)$$

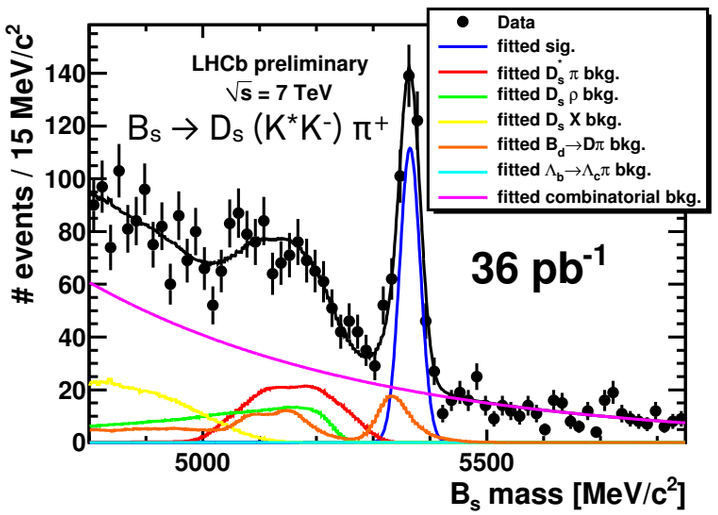
$\sin(2\beta) \equiv \sin(2\phi_1)$

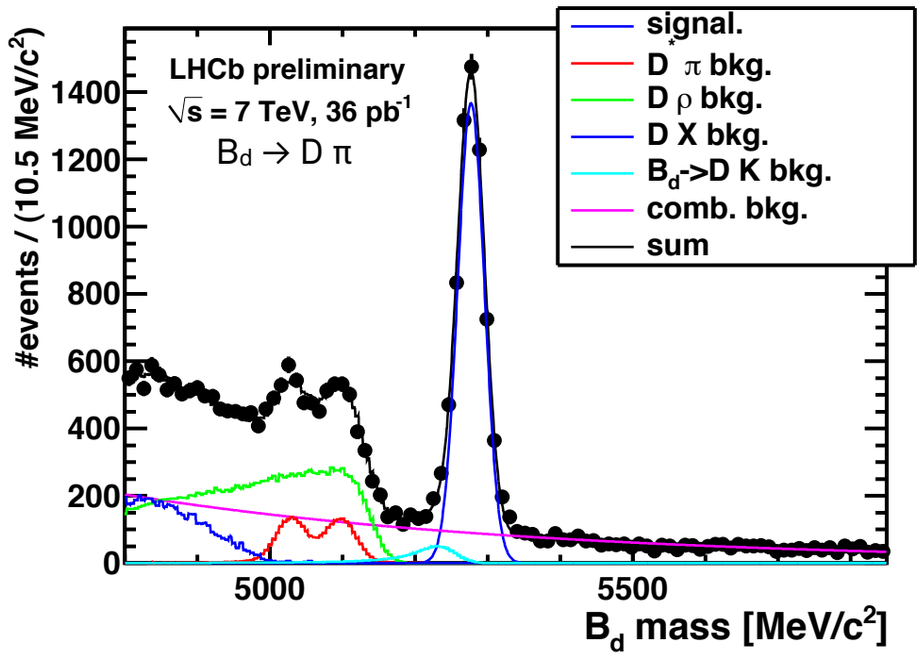
HFAG
Beauty 2011
PRELIMINARY

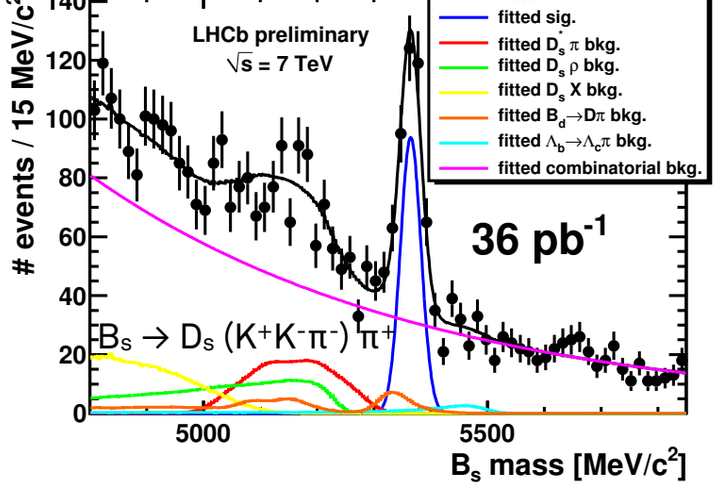


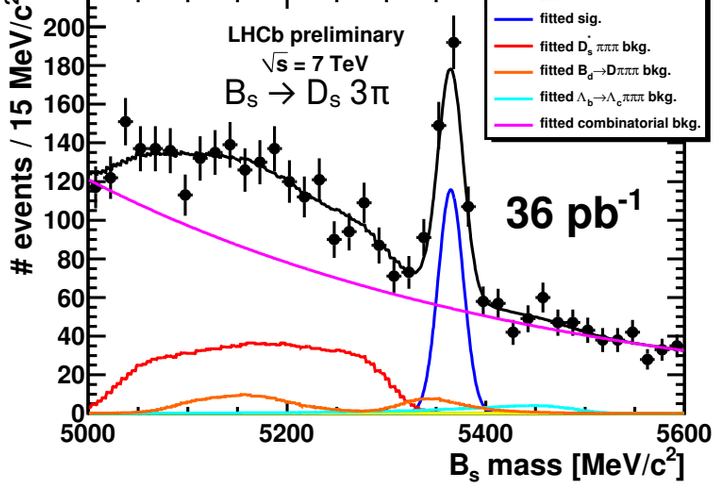
Δm_d and Δm_s – mass plots









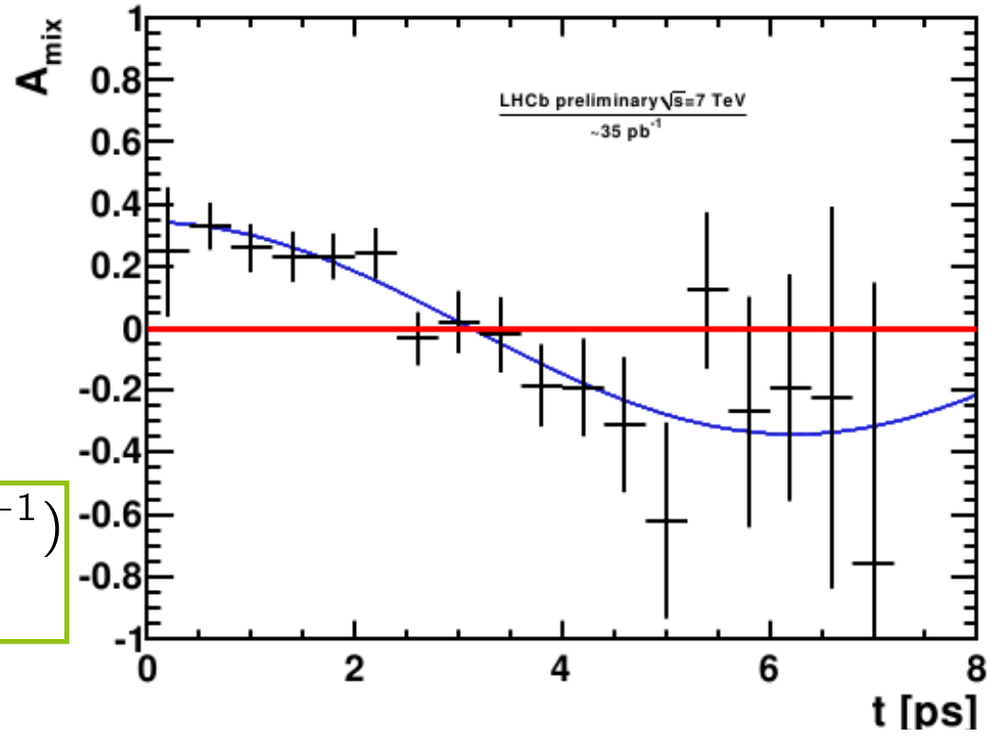


Δm_d and Δm_s

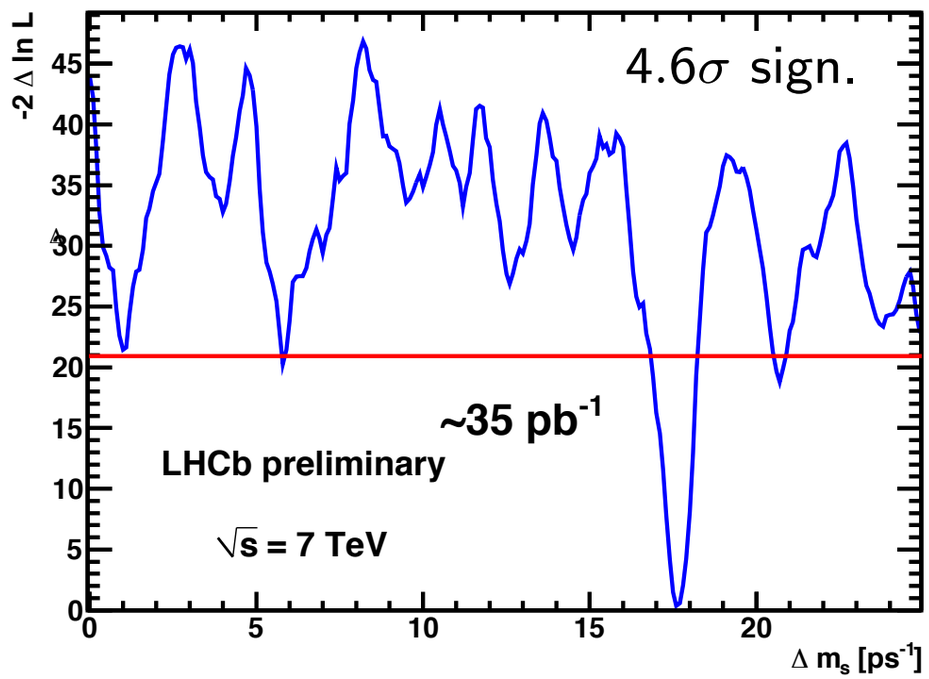
- result for Δm_d compatible with world average:
  (0.507 ± 0.005) ps (PDG 2010)
- Δm_s measurement competitive with CDF

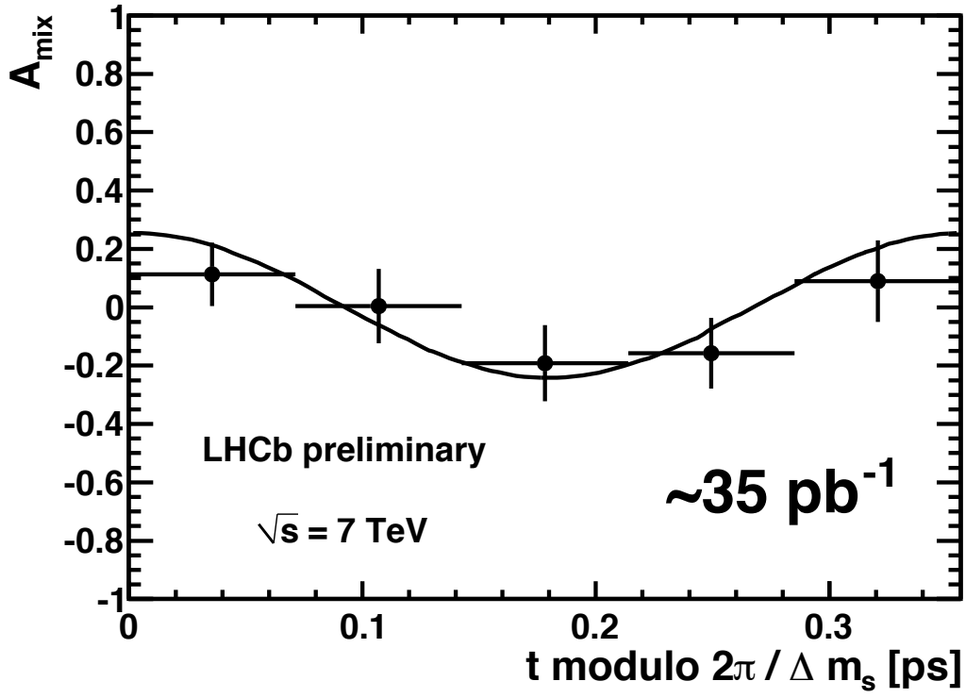
LHCb $\Delta m_d = (0.499 \pm 0.032(stat.) \pm 0.003(syst.))\text{ps}^{-1})$
$\Delta m_s = (17.63 \pm 0.11(stat.) \pm 0.04(syst.))\text{ps}^{-1})$

CDF $\Delta m_s = (17.77 \pm 0.10(stat.) \pm 0.07(syst.))\text{ps}^{-1})$



Δm_d



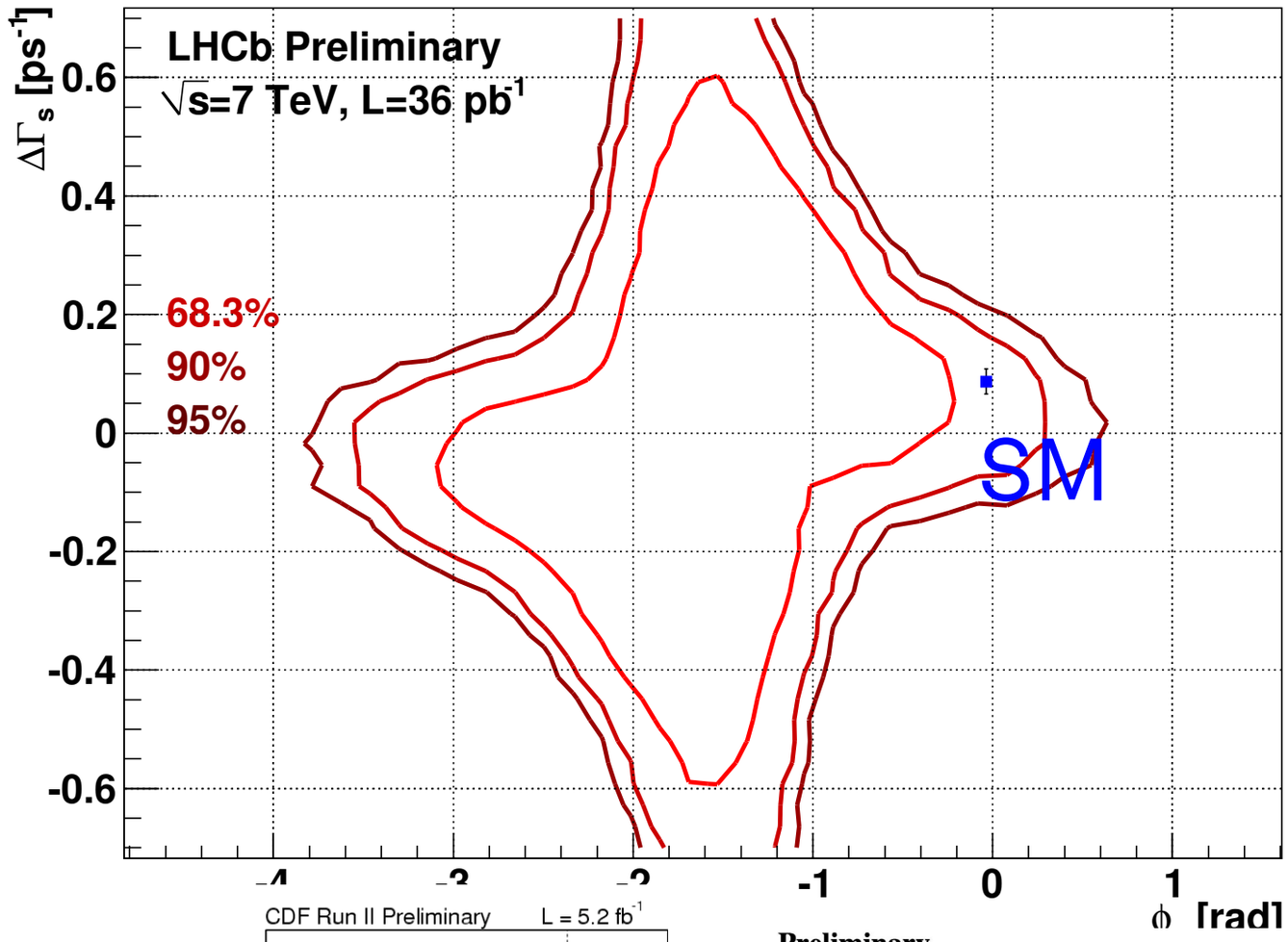


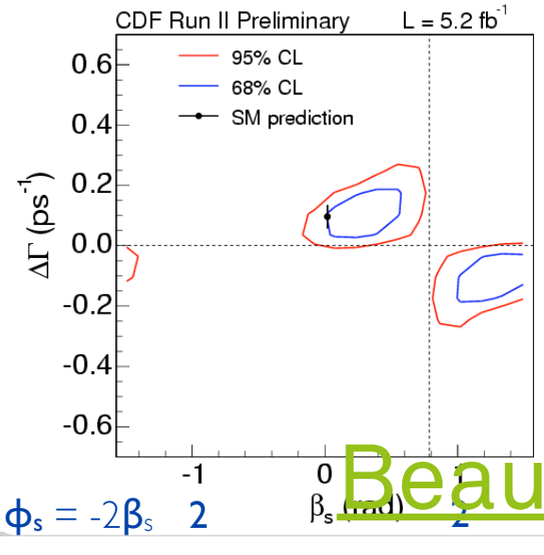
Δm_s

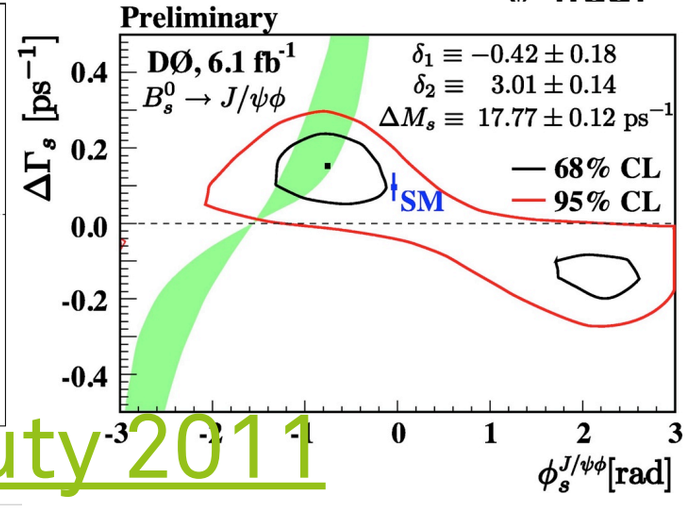
$B_s \to J/\psi \phi$

- 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



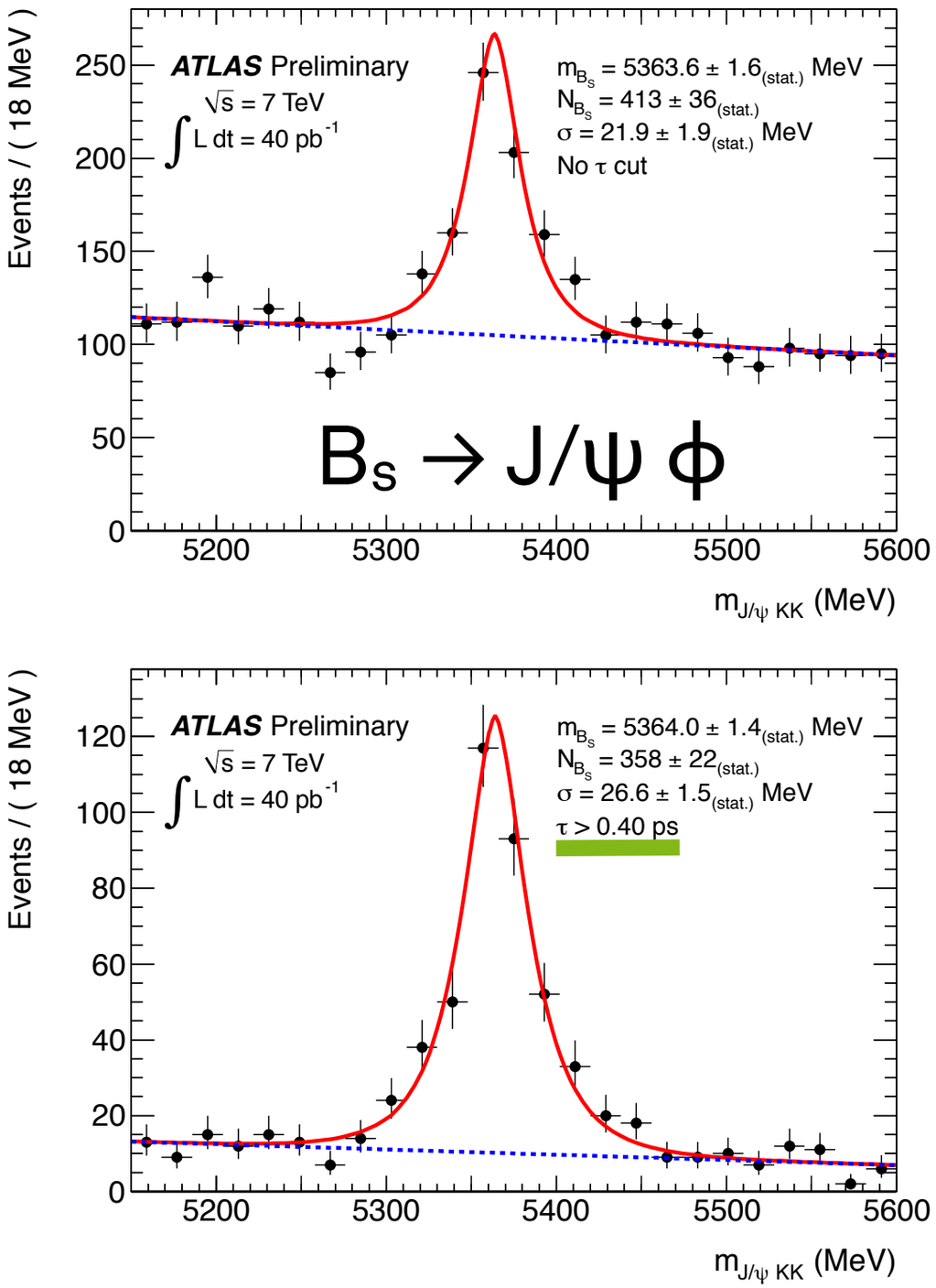


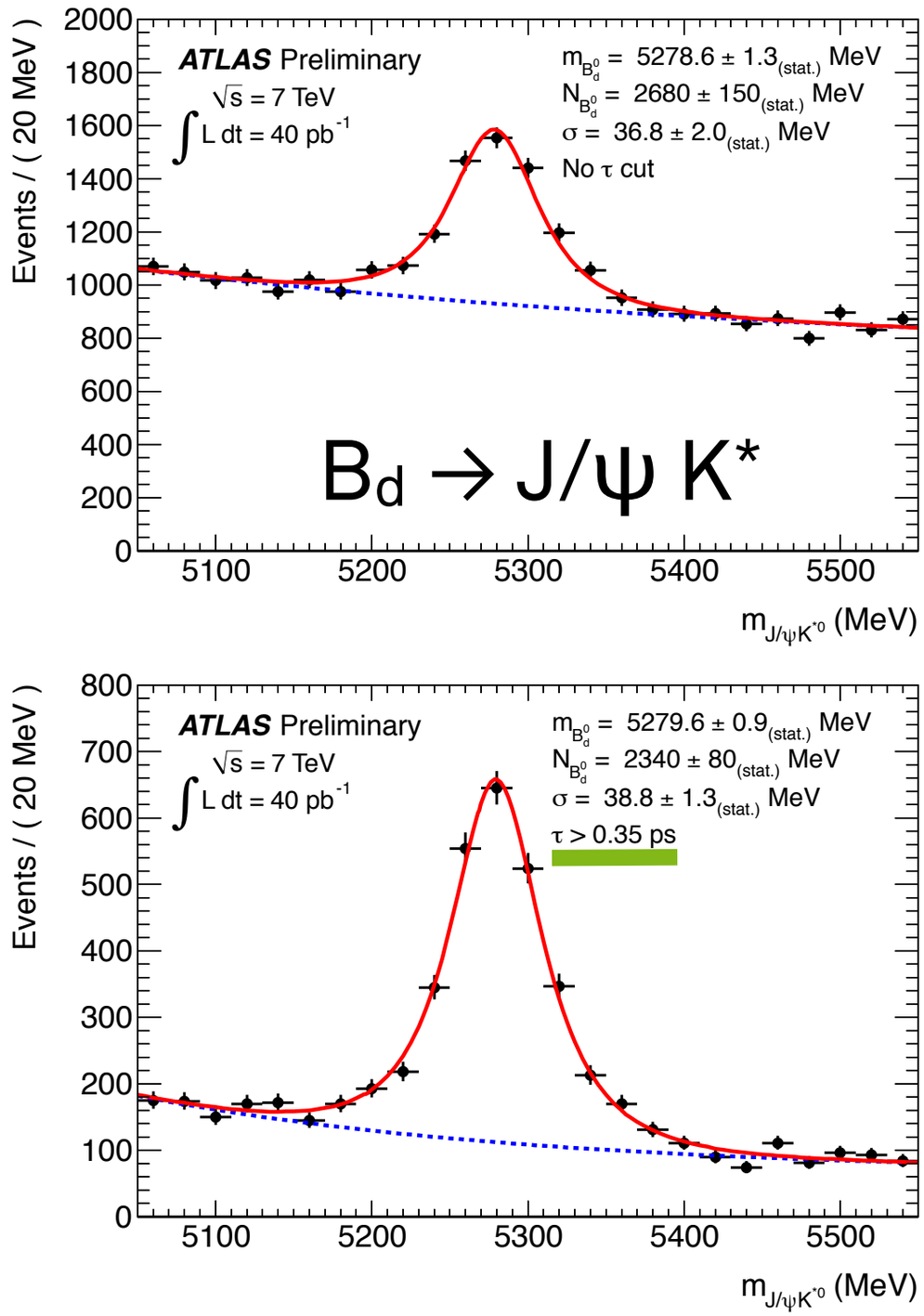


Beauty 2011

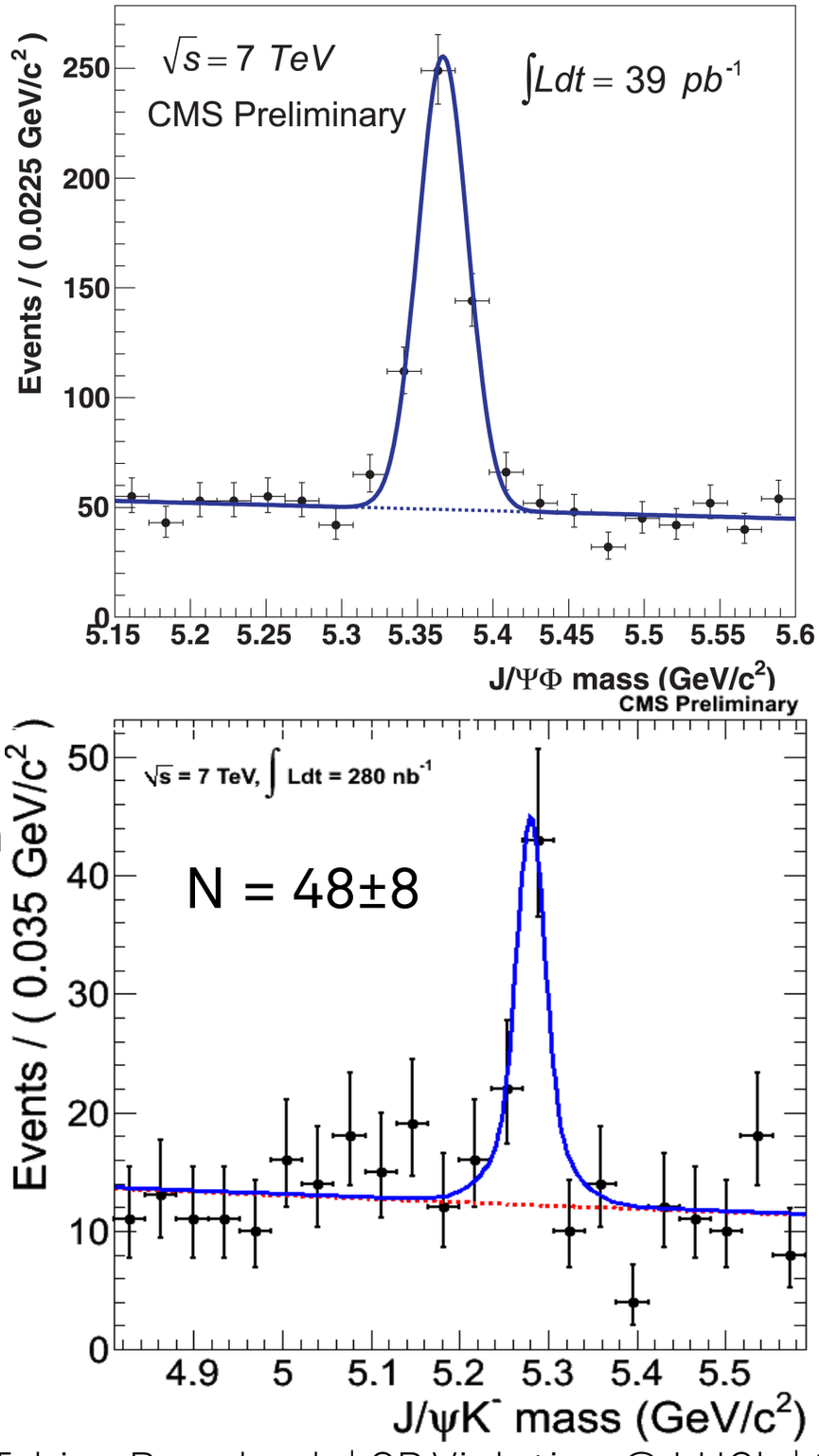
ATLAS

ATLAS CONF 2011-050

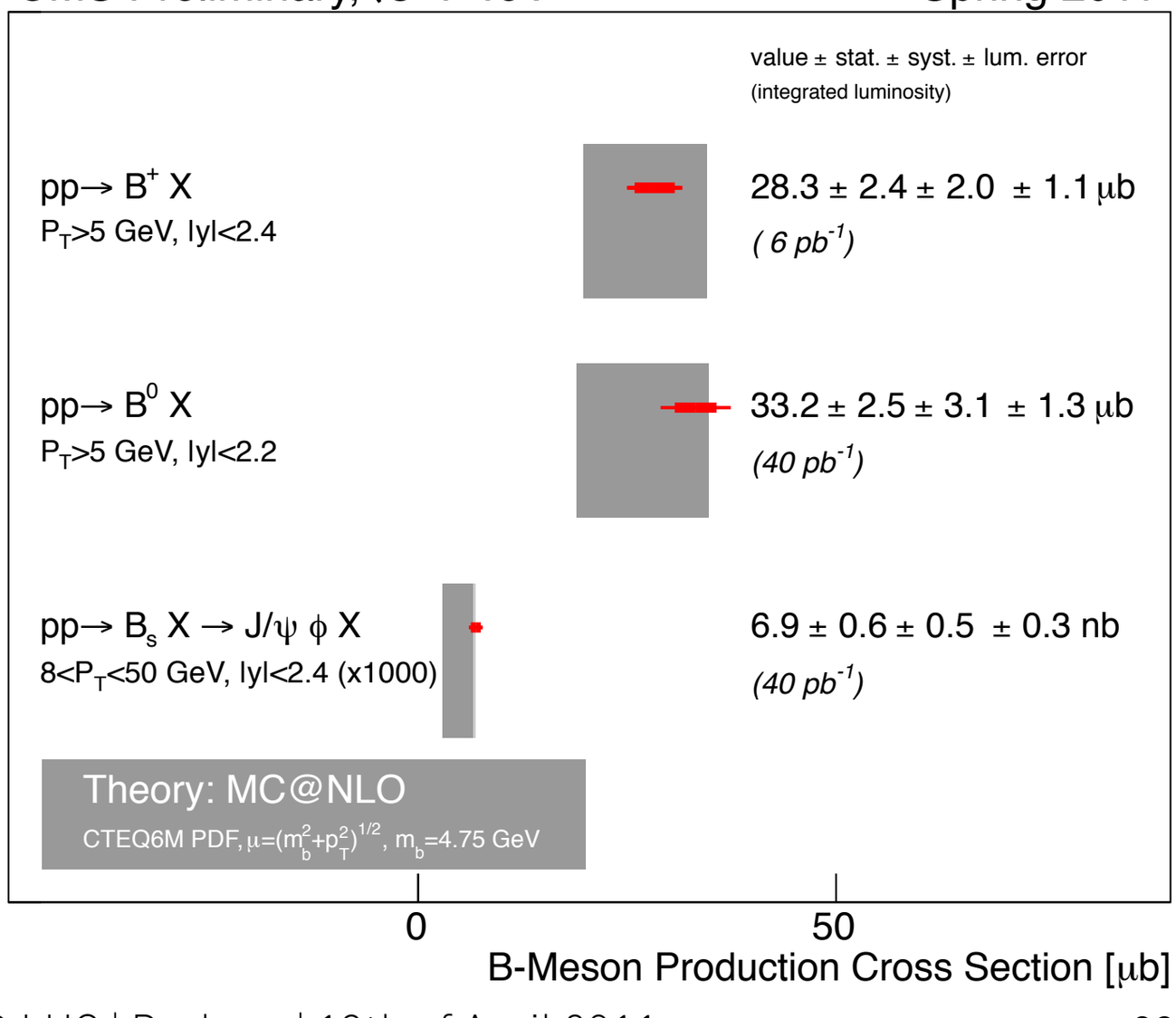




CMS – B physics results

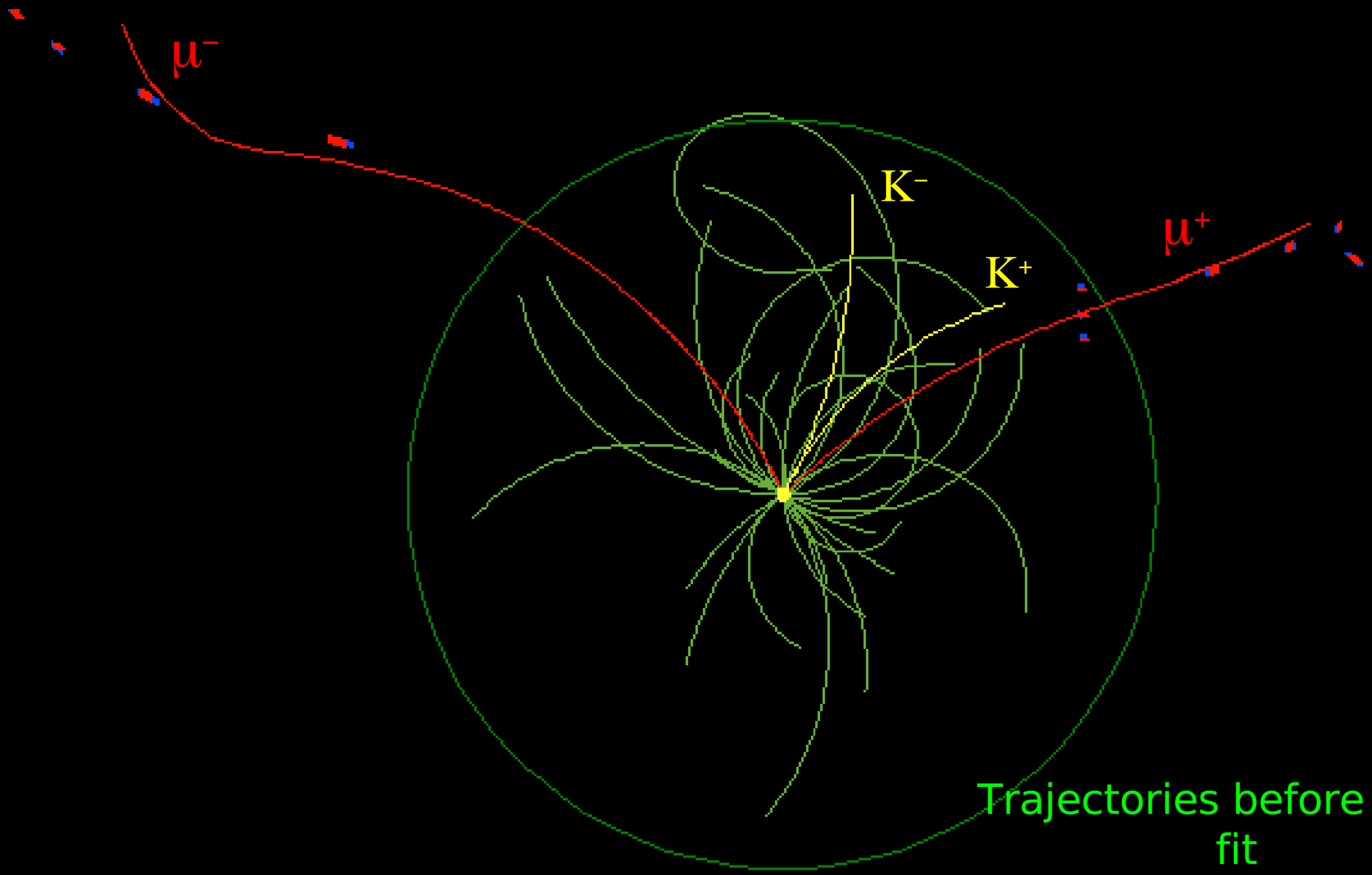


$\mu_{gauss} = 5.3670 \pm 0.0012$ GeV/c^2
$\sigma_{gauss} = 16.4 \pm 1.2$ MeV/c^2
$N_{signal} = 377 \pm 26$
$N_{BG} = 978 \pm 36$
χ^2/ndof = 0.91
S/√(S+B) ≈ 10
S/B ≈ 0.4



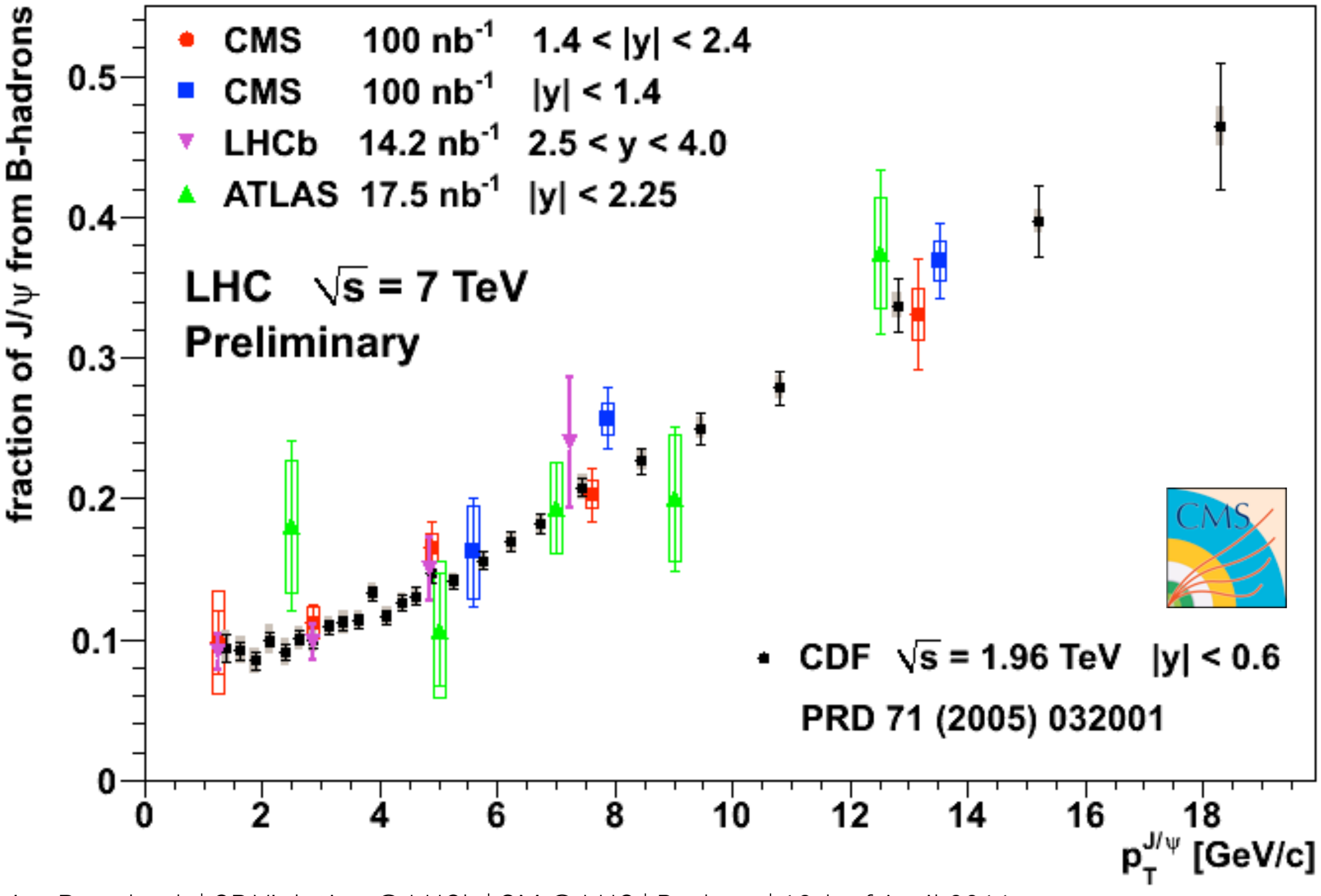
CMS Experiment at LHC, CERN
Data recorded: Sun Jul 4 01:33:41 2010 EDT
Run/Event: 139364 / 20750462
Lumi section: 20

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



Trajectories before vertex fit
with $p_T > 0.3$ GeV/c in the vicinity of the PV

LHC compared to CDF



Conclusions and Outlook

- remarkable performance of machine and detector in 2010, expecting results from ATLAS and CMS soon
- many encouraging results on first 37 pb^{-1} of data
  - results on B_s are competitive with CDF already, because of excellent time resolution, worlds best measurement of ϕ_s expected for 2011
  - expect significant improvement for sin 2β with statistics of 2011(+ 2012) run
  - extraction of γ from loops in preparation
- good tagging performance
- small systematics will decrease further with a larger 2011 dataset