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Fakultät Physik
Experimentelle Physik 5

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Search for New Physics in CP violation measurements @LHCb

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on behalf of the LHCb Collaboration

2nd International Conference on Particle Physics, Istanbul

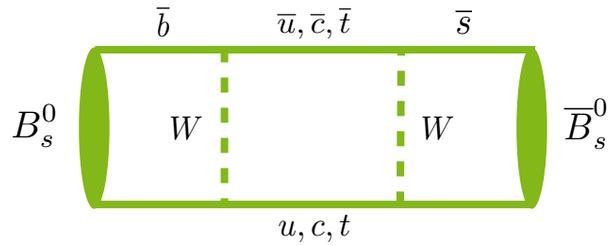
LHCb Physics

Main Goal:
Search for New Physics (NP) through precision tests of the Standard Model (SM)

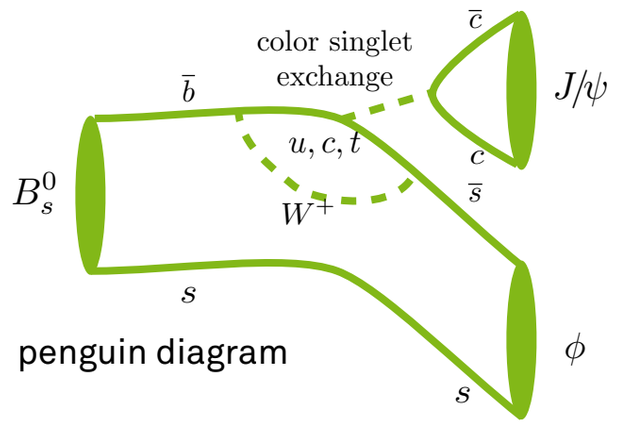
Idea:
Reveal small deviations from SM predictions with precision measurements

- Indirect search for New Physics
  - in rare decays (see talk by Francesco Dettori)
  - in CP violating processes in the B and D sector (this talk)

- Why CP violating processes?
  - CP violation from interference of tree and loop mediated processes



box diagram



penguin diagram

  - NP particles can alter SM prediction of CP violation by introducing additional phases in loop processes

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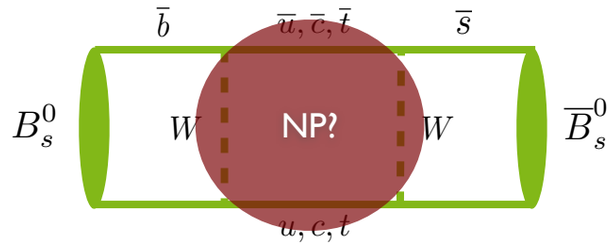

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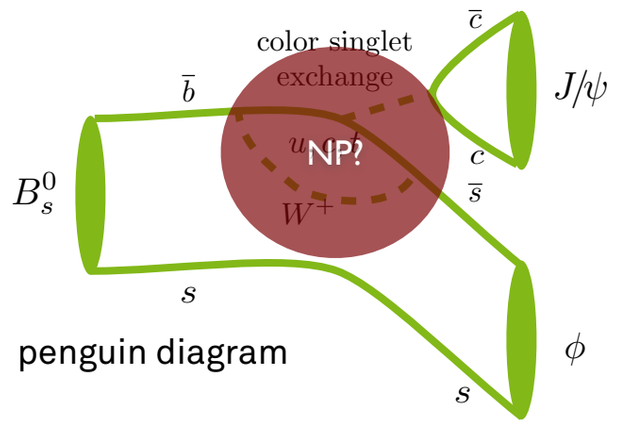

penguin diagram

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Detector Performance

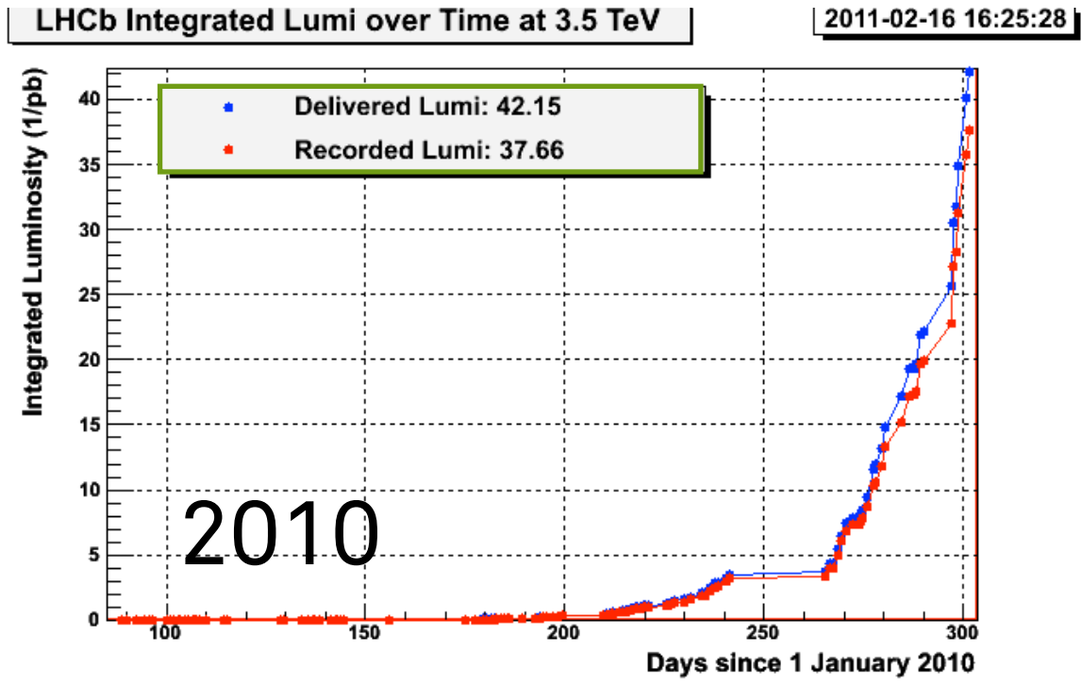
see Talk by S. Monteil

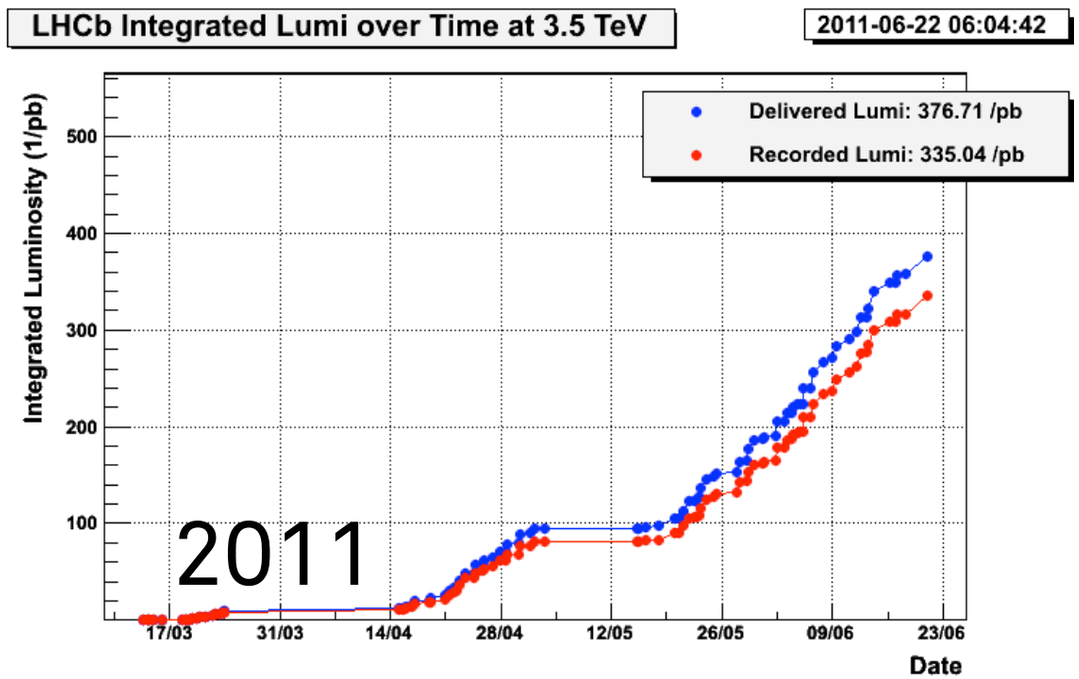
- Data taking at $\sqrt{s}$ = 7 TeV

- subsystems work fine
- data taking efficiency >85%

- higher pile-up
  - more b hadrons
  - more tracks, more background

- **2010: collected ~37 pb^{-1}**
- expect ~1 fb^{-1} in 2011





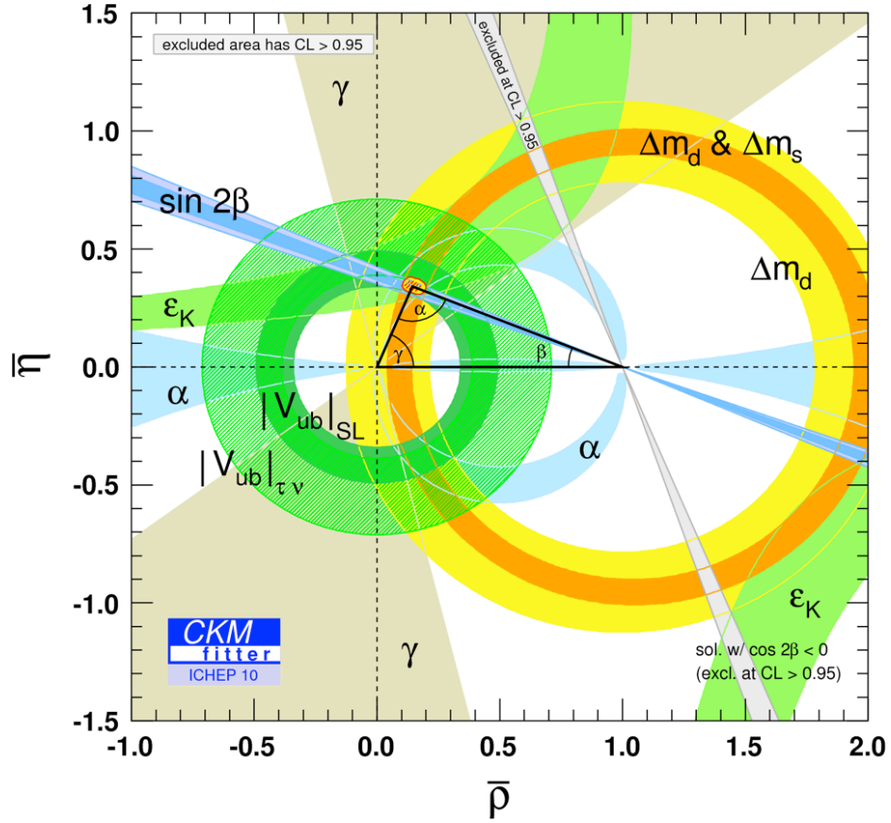
CP Violation in the SM

CP violation in the SM is described by the CKM mechanism

- parameterised by the complex unitary CKM matrix

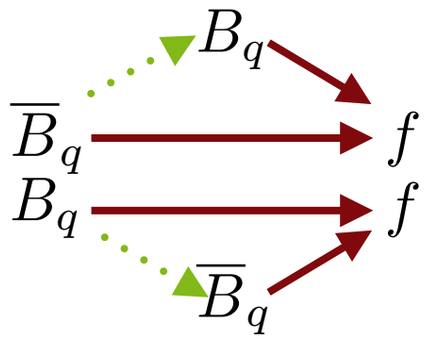
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V_{\mathrm{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} .$$

- construct unitarity triangles
  - e.g. $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$
    $V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$
  - connect observables of various processes/decays (over-constrained!)
  - inconsistency of measurements => hint for New Physics



CP Violation

- Types
  - direct CPV
  - CPV in mixing
  - CPV in interference of mixing and decay
    - neutral B mesons: B_d and B_s
    - fast oscillation in B_s, slow oscillation in B_d



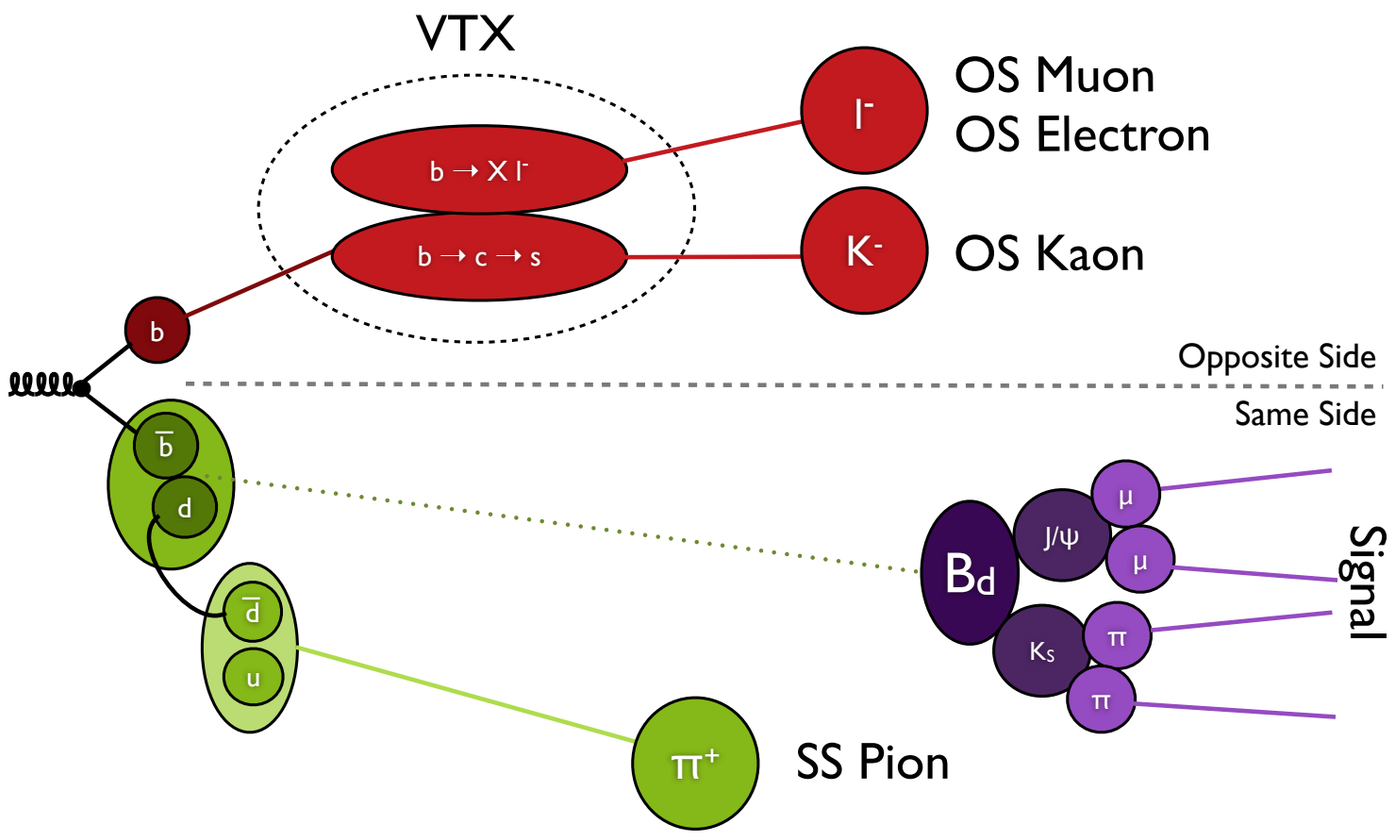
    - different CKM angles accessible in B_s and B_d
    - time-dependent asymmetry

$$\mathcal{A}_{\mathcal{CP}}(t) \quad = \quad \frac{\Gamma(\overline{B}^0_q(t) \to f) - \Gamma(B^0_q(t) \to f)}{\Gamma(\overline{B}^0_q(t) \to f) + \Gamma(B^0_q(t) \to f)}$$

    - Crucial information: Initial flavour?

Flavour Tagging

- infer information on production state (tag) from
  - inclusive reconstruction of “sister” b quark decay (opposite side)
  - search for fragmentation remnants of signal B (same side)
- per-event estimation of mistag probability

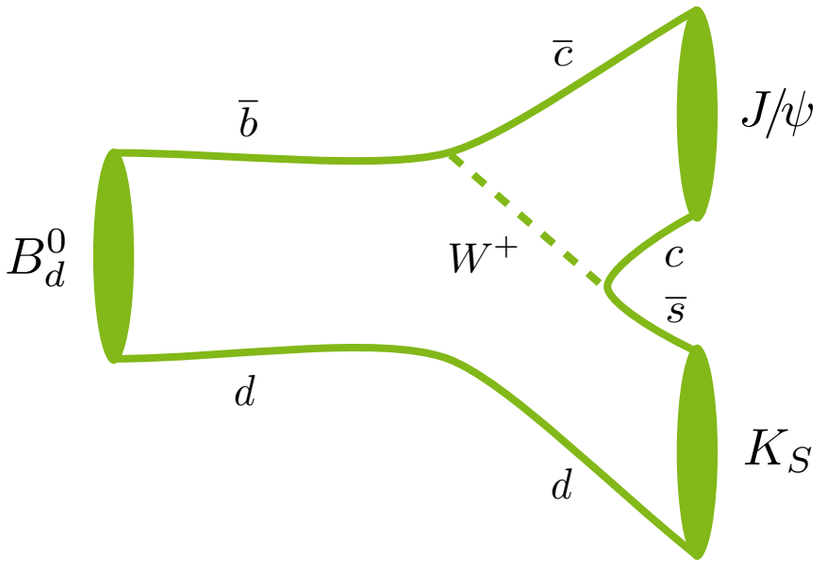


- need to calibrate flavour taggers on data
- measure and control mistag probability of tagging algorithms
- sensitivity of measured asymmetry is directly related to effective tagging efficiency $\varepsilon_{\rm eff} = \varepsilon_{\rm tag} D^2$

$$\varepsilon_{\rm tag} = \frac{N_R + N_W}{N_R + N_W + N_U} \qquad \omega = \frac{N_W}{N_R + N_W}$$

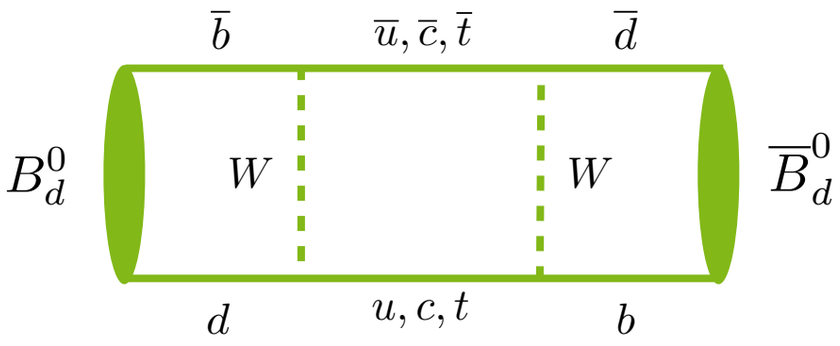
$$\mathcal{A}_{\mathcal{CP}}^{\rm meas}(t) = \underbrace{(1-2\omega)}_{D}\,\mathcal{A}_{\mathcal{CP}}(t)$$

Mixing and Decay in $B_d \to J/\psi\, K_S$



- Time dependent asymmetry

$$\mathcal{A}_{J/\psi K^0_S}(t) = \frac{\Gamma(\overline{B}^0 \to J/\psi K^0_S) - \Gamma(B^0 \to J/\psi K^0_S)}{\Gamma(\overline{B}^0 \to J/\psi K^0_S) + \Gamma(B^0 \to J/\psi K^0_S)}$$
$$= S_{J/\psi K^0_S} \sin(\Delta m_d t) - C_{J/\psi K^0_S} \cos(\Delta m_d t)$$



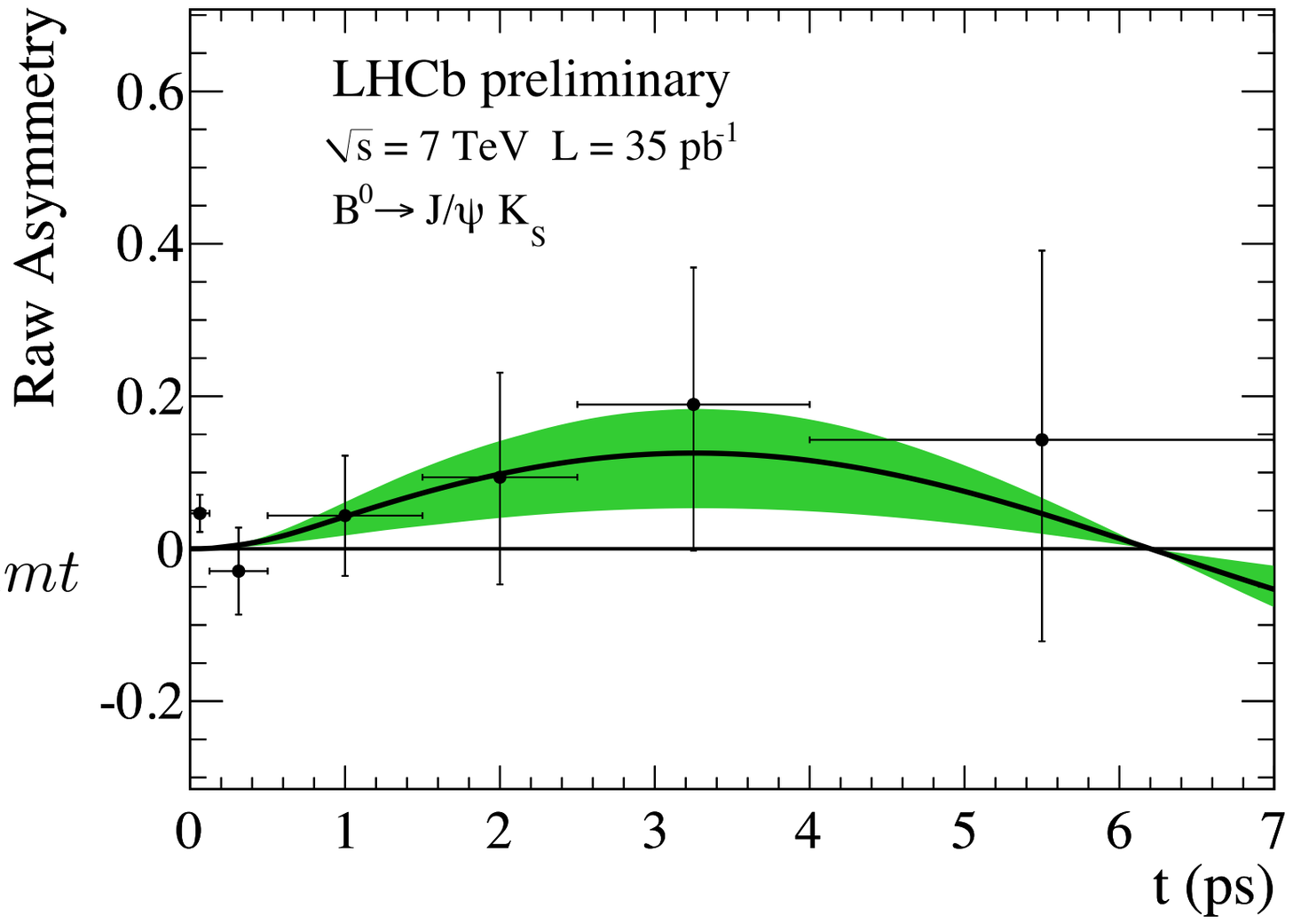
- Assuming $C_{J/\psi K^0_S} = 0$

$$S_{J/\psi K^0_S} = \sin 2\beta$$

sin2β from $B_d \to J/\psi K_S$

- sin2β well measured by B factories
- serves as reference measurement for LHCb
- first measurement of time dependent CP asymmetries @ LHCb

$$\mathcal{A}_{\mathcal{CP}}^{\mathrm{meas}}(t) \approx D \, \sin 2\beta \, \sin \Delta m t$$



- best measurement of sin2β at a hadron machine
- dominated by statistical error
- systematic uncertainty will decrease in future

$$\sin 2\beta = 0.53^{+0.28}_{-0.29}(stat.) \pm 0.08(syst.)$$

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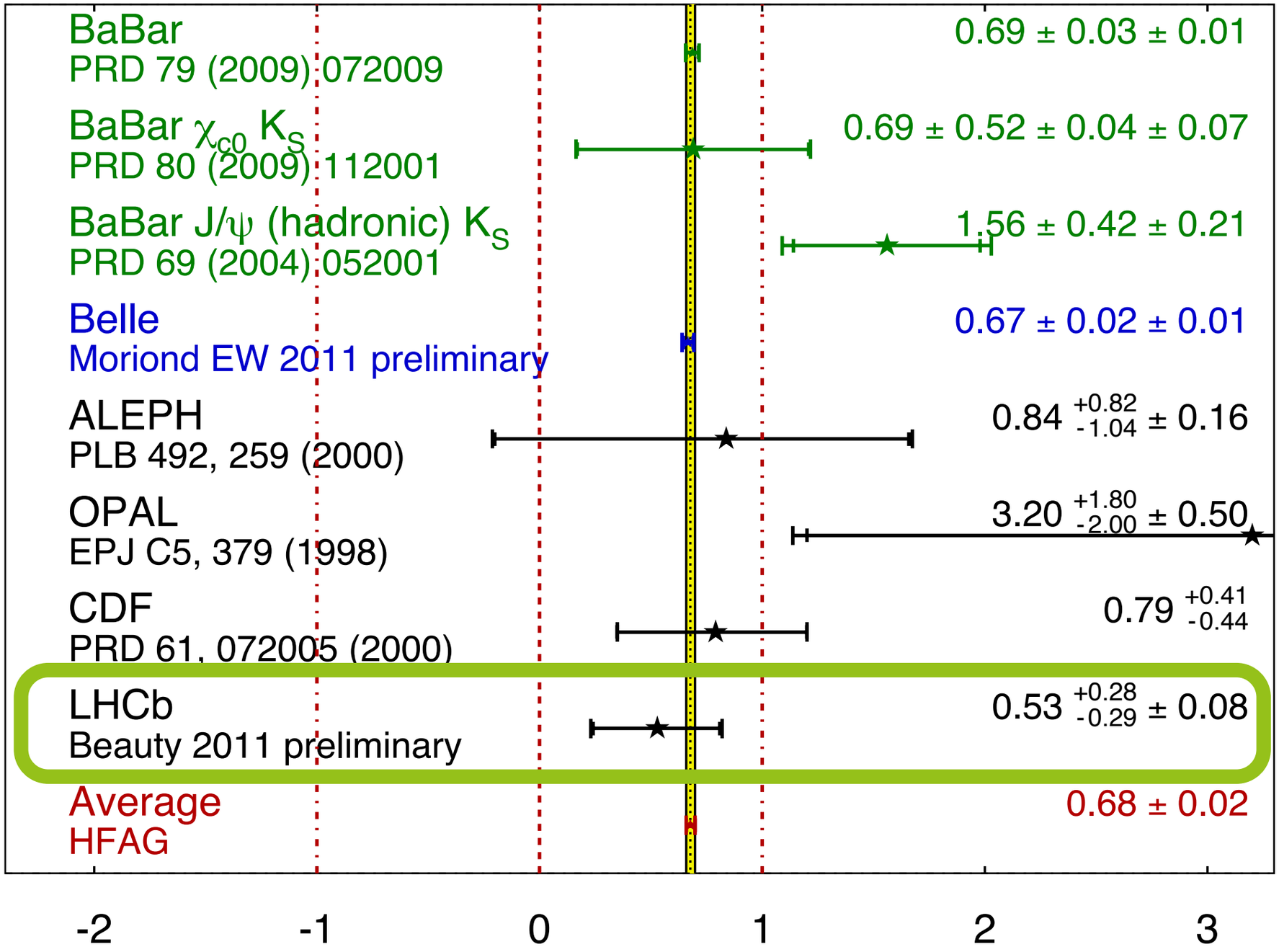
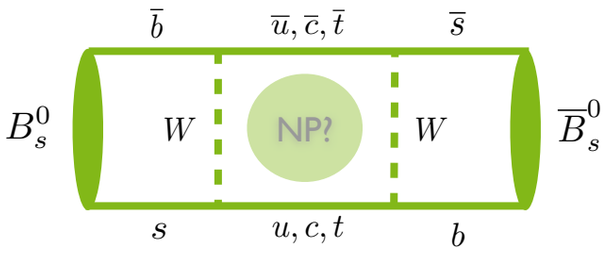
$\sin(2\beta) \equiv \sin(2\phi_1)$

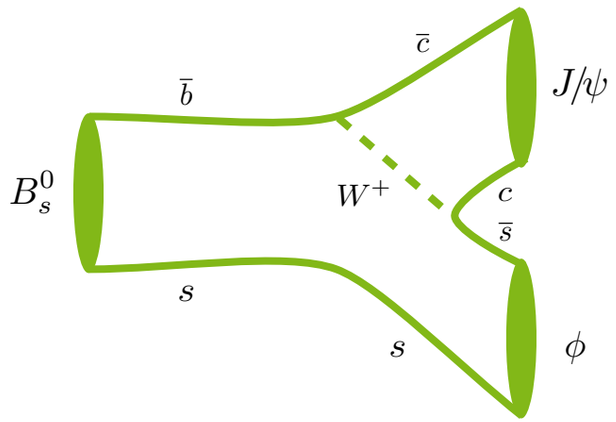
HFAG
Beauty 2011
PRELIMINARY

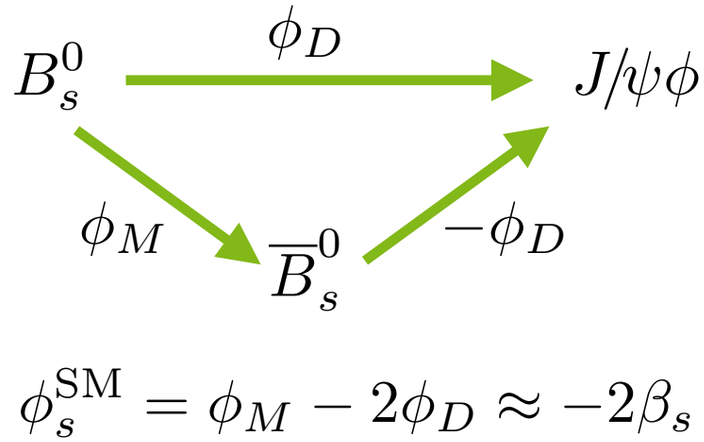


CP measurement in B_s system

- ϕ_s in $B_s \to J/\psi\, \phi$.
  - **What is ϕ_s?** CP violating phase in interference of mixing and decay of B_s



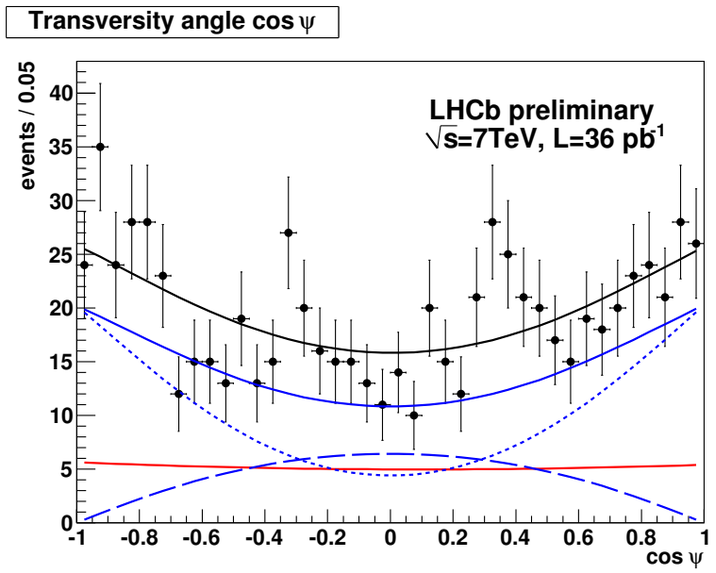




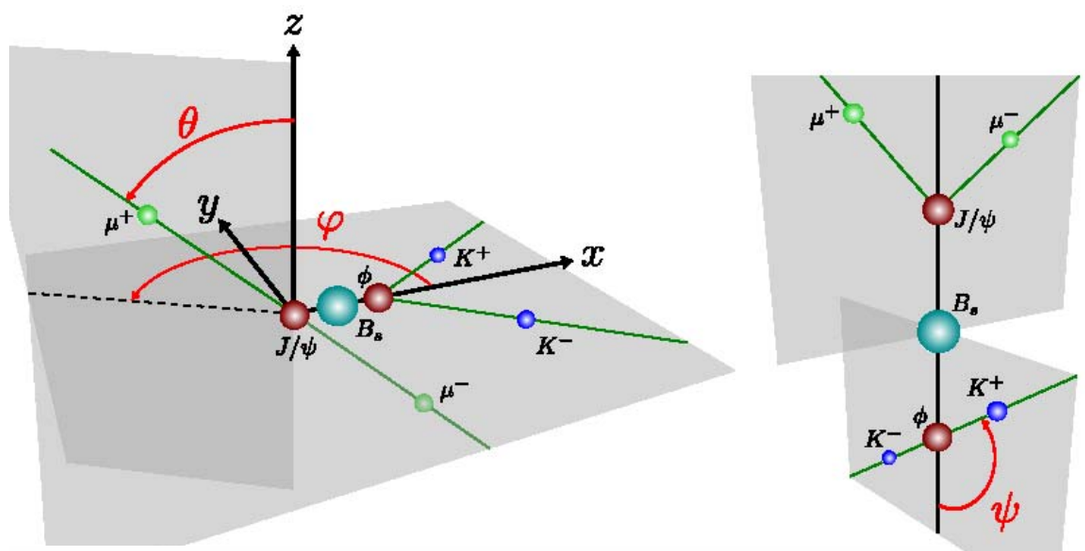
  - **Test:** Is $\phi_s \neq \phi_s^{SM} = -2\beta_s$?
    - precise SM prediction $2\beta_s = (0.0363 \pm 0.0017)$ rad (**indirect**)
    - if **direct** measurement of ϕ_s shows deviation from SM prediction: New Physics!

Measurement of ϕ_s

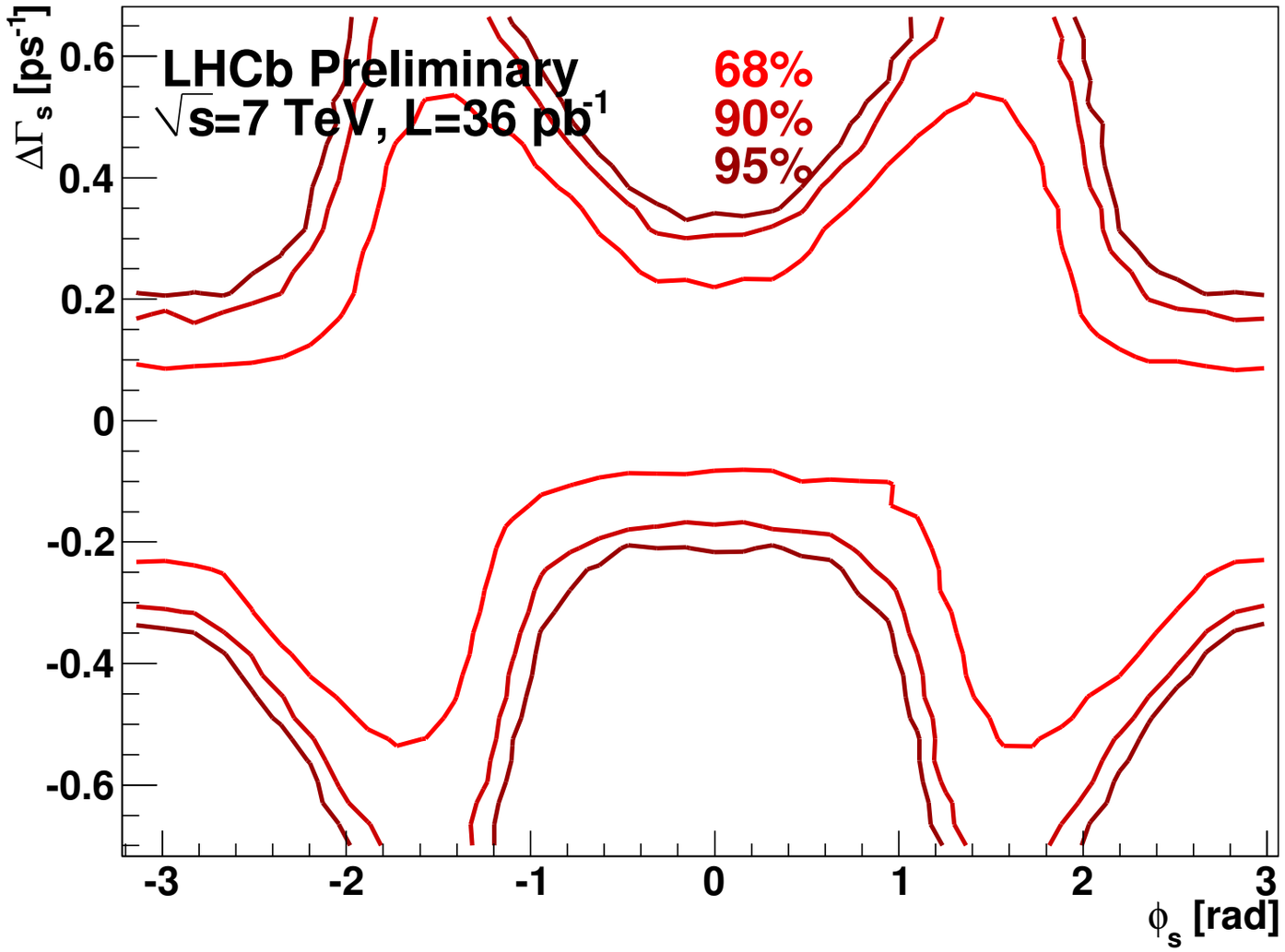
- $B_s \to J/\psi\,\phi$ is a $P \to VV$ decay
  - final state of is admixture of different CP even/odd eigenstates (different angular momenta)
  - three different polarization amplitudes
  - use transversity angles to disentangle CP eigenstates



- use a four dimensional pdf in time and three transversity angles to extract ϕ_s and $\Delta\Gamma_s$



$B_s \to J/\psi\,\phi$ - Untagged Analysis



- no constraint on ϕ_S [LHCb CONF 2011-002]
- tagging needed to reduce four-fold to two-fold ambiguity

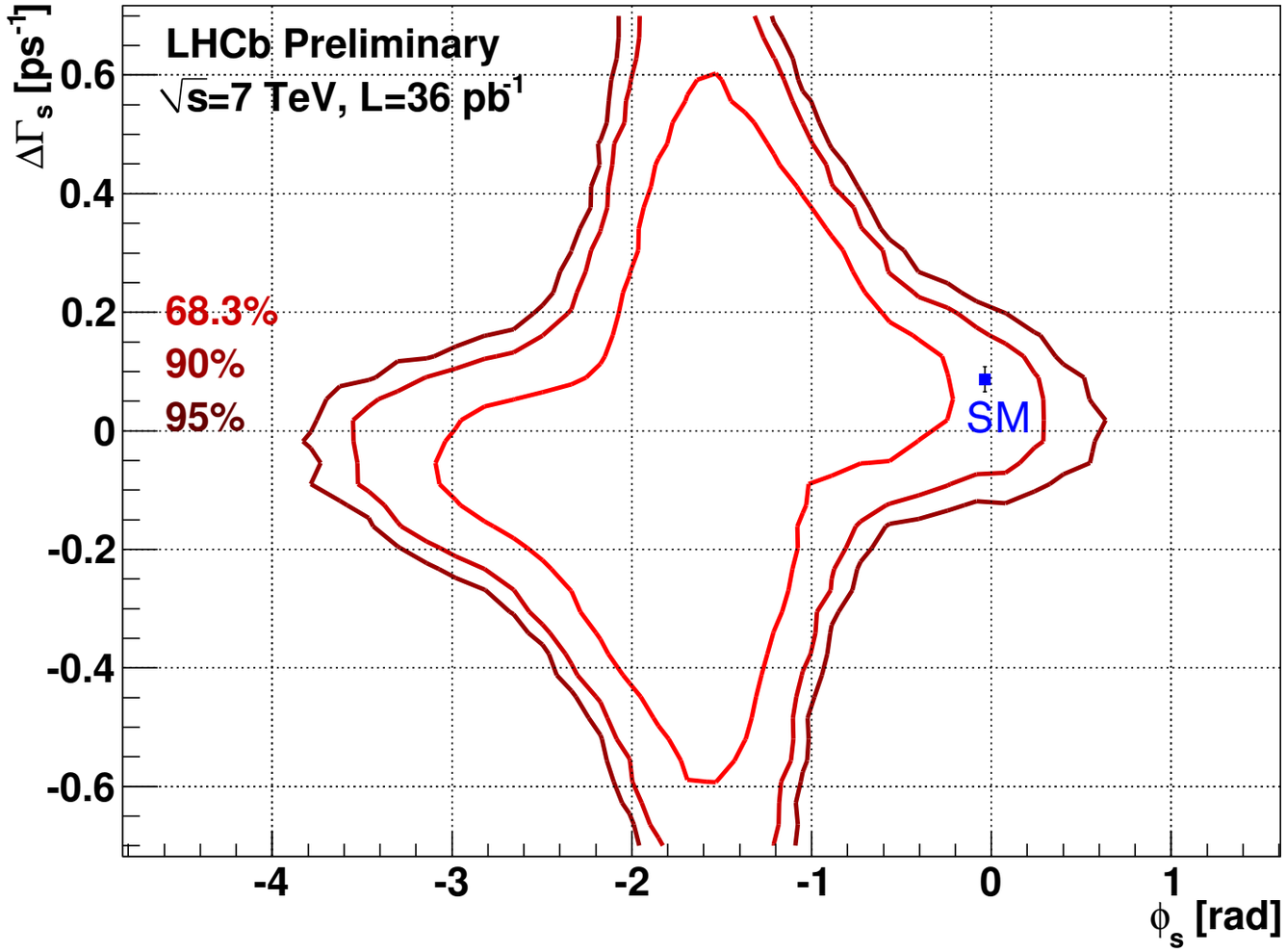
$B_s \to J/\psi\,\phi$ - Tagged Analysis

- first LHCb constraint on ϕ_s $\quad -2.7 < \phi_s < -0.5$ @ 68% CL

- ambiguity reduced to two fold by use of tagging information

- systematics small compared to statistical uncertainties

- prospect for 2011 data
  - $\sigma(\phi_s) \approx 0.13$ rad



CDF	$[0.02, 0.52] \cup [1.08, 1.55]$
D0	$-0.76^{+0.38}_{-0.36}(\text{stat}) \pm 0.02(\text{syst})$

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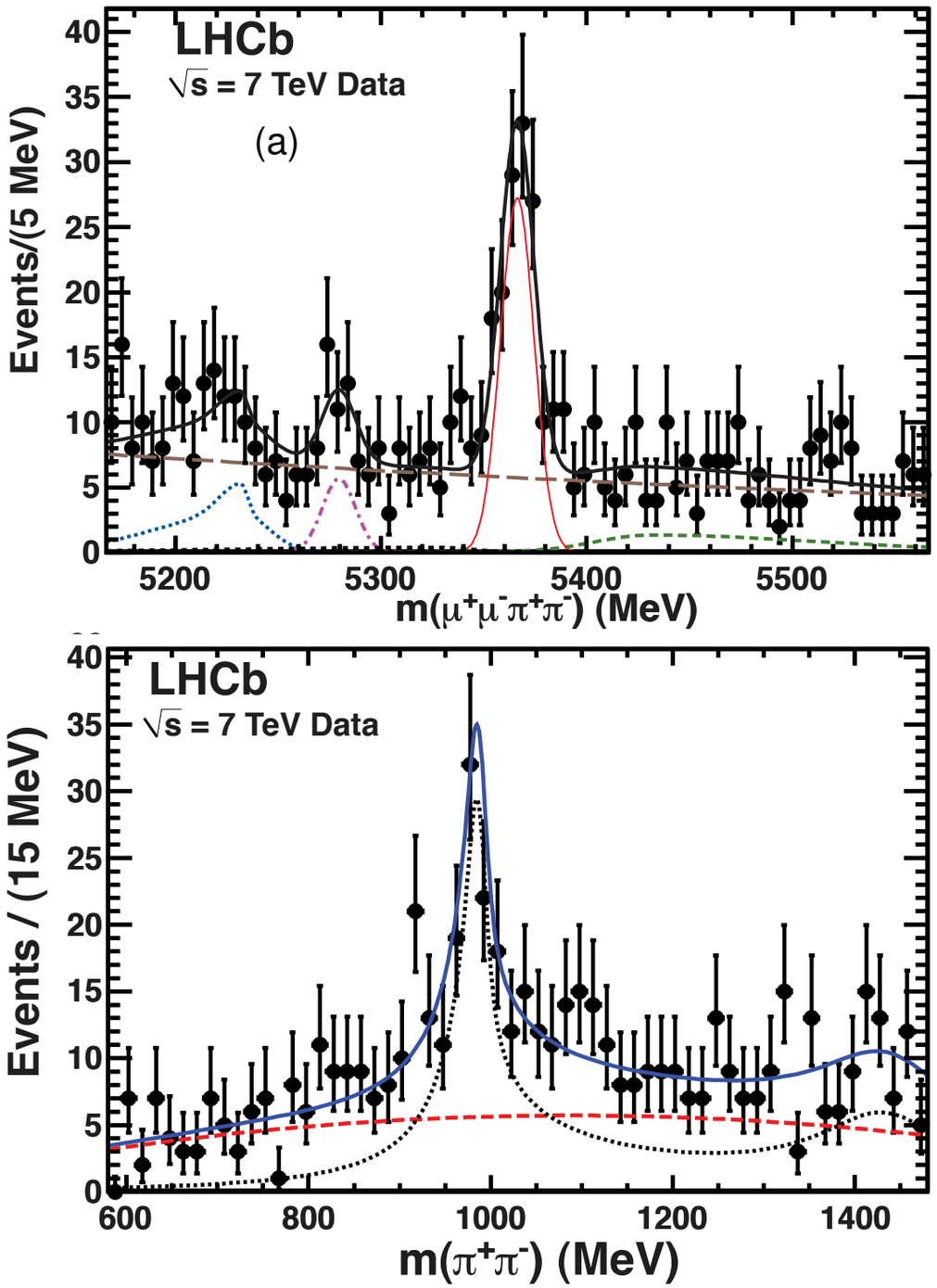
$B_s \to J/\psi\, f_0(980)$ – first observation

- 12.8σ significance
- 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

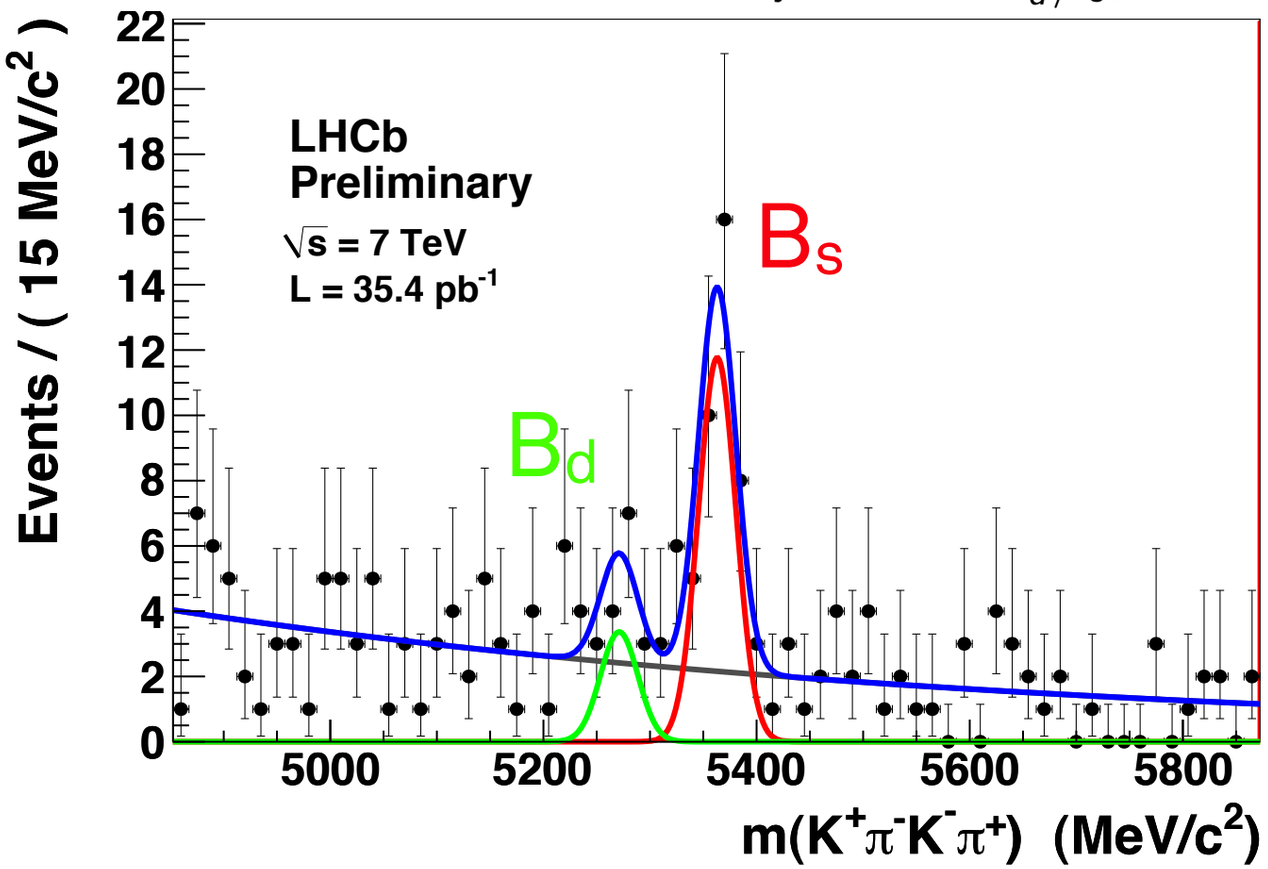


- Future plans:
  - alternative measurement of ϕ_s
  - pure CP final state
  - no angular analysis needed

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

- 7.4σ significance
- Penguin decay like $B_s \to \phi\phi$
- sensitivity to NP in mixing box and penguin diagram
- currently no measurement of CPV

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



LHCb CONF 2011-019

Conclusion and Outlook

- analyses on 2010 dataset show excellent performance of LHCb
  - first CP violation measurements
  - tagged, angular, time-dependent CP analyses
  - new decay modes discovered and studied

- LHCb measurements in 2011 will contribute significantly in constraining the SM
  - Expect world‘s best measurements of ϕ_s with 2011 dataset!
  - Stay tuned for γ!
  - Interesting CP channels under investigation.

Thank you for listening!

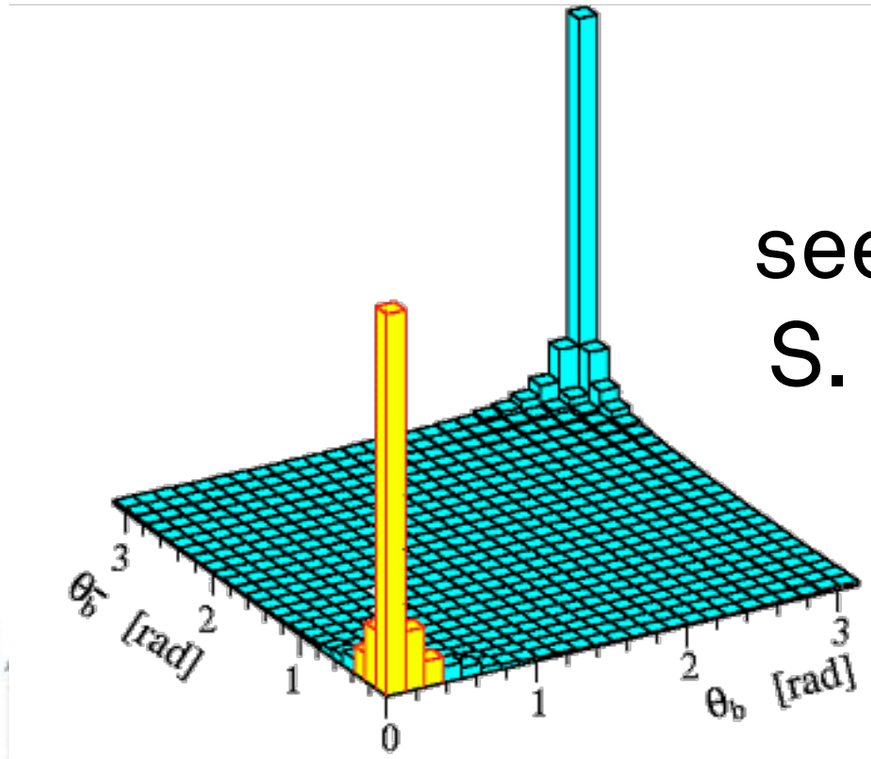
LHCb Detector

- one arm forward spectrometer
- covers $1.9 < \eta < 4.9$
- b pair production correlated in forward/backward direction

- excellent lifetime resolution (~50 fs)
  - boosted particles
  - extraordinary vertex resolution

- tracking stations before and after dipole magnet

- particle identification
  - two RICH detectors
  - calorimetry
  - muon system



see talk by S. Monteil