Prospects for CP violation in $B_s \to J/\psi\,\phi$ from first LHCb data.

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on behalf of the LHCb collaboration

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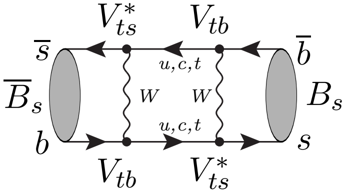
B–Meson Mixing

- Neutral B mesons mix due to the presence of box diagrams.
- Described by an effective Hamiltonian.
- Solutions to the Schrödinger equations give two mass eigenstates: heavy and light.

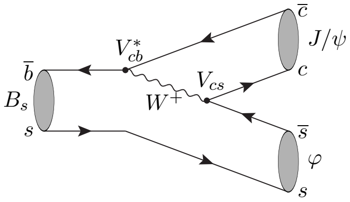
$$\imath \frac{\partial}{\partial t} \begin{pmatrix} |B_s(t)\rangle \\ |\bar{B}_s(t)\rangle \end{pmatrix} = \left(\boldsymbol{M} - \imath \frac{\boldsymbol{\Gamma}}{2} \right) \begin{pmatrix} |B_s(t)\rangle \\ |\bar{B}_s(t)\rangle \end{pmatrix}$$

- mass difference: Δm_s
  - CDF: $17.7 \pm 0.07 \text{ps}^{-1}$
- decay width difference: $\Delta\Gamma_s$
  - CDF: $0.075 \pm 0.045 \text{ps}^{-1}$



CP violation in $B_s \to J/\psi\,\phi$

- Both B_s and $\bar{B}_s$ can decay to $J/\psi\ \phi$.
- This yields the possibility of time–dependent CP violation in the interference between mixing and decay.
- SM prediction:
  - A_{CP} suppressed: $\sin(\phi_s^{J/\psi\phi}) = -0.04$
- Many models for new physics significantly enhance $\phi_s^{J/\psi\phi}$.

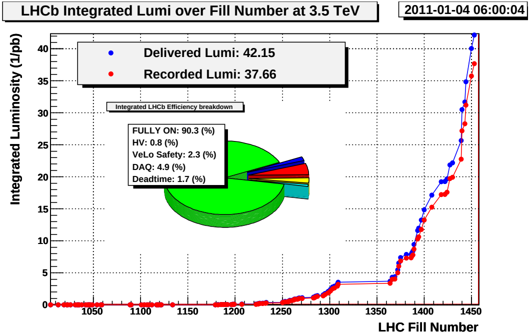


Challenges

- B_s system oscillates rapidly.
  - Requires very good proper–time resolution to resolve oscillations
- $B_s \to J/\psi\,\phi$ is a P→VV decay
  - The final state is a mixure of CP–even and CP–odd states.
  - Angular analysis required to be able to statistically disentangle them.
- $\Delta\Gamma_s$ cannot be neglected.
  - Correlations between proper time and angular distributions.
- Flavour tagging required.
  - Hard in an hadronic environment.
  - Becomes harder with higher pile–up.

Luminosity and pile–up

- Luminosity reached $1.7 * 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- $\sim 37\mathrm{pb}^{-1}$ recorded.
- $\mathcal{O}(85\%)$ of design luminosity with $\mathcal{O}(12\%)$ of the bunches.
- $\sim$ 2 pp interactions per visible event.
- This is close to the foreseen values for the LHCb upgrade.



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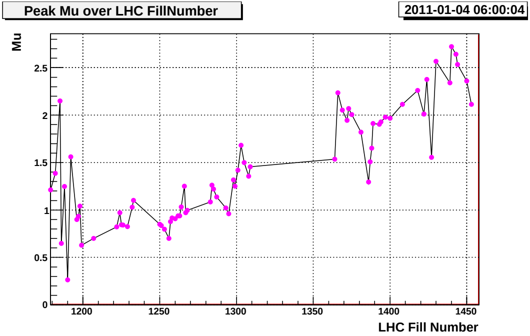
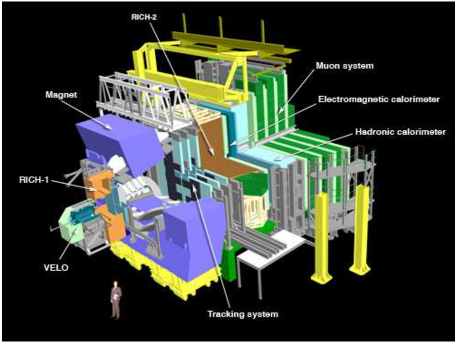
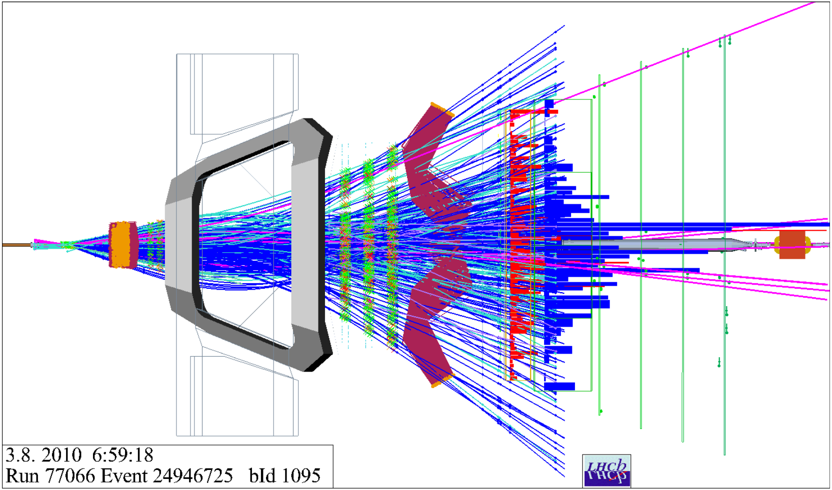


LHCb

- Vertex Detector
  Vertex reconstruction
  Proper time measurement
- Tracker
  Momentum resolution
- RICH
  K–π separation
- Calorimeters
  Energy mesurement
  π^0, e, γ identification
- Muon detector
  μ identification



Event Display



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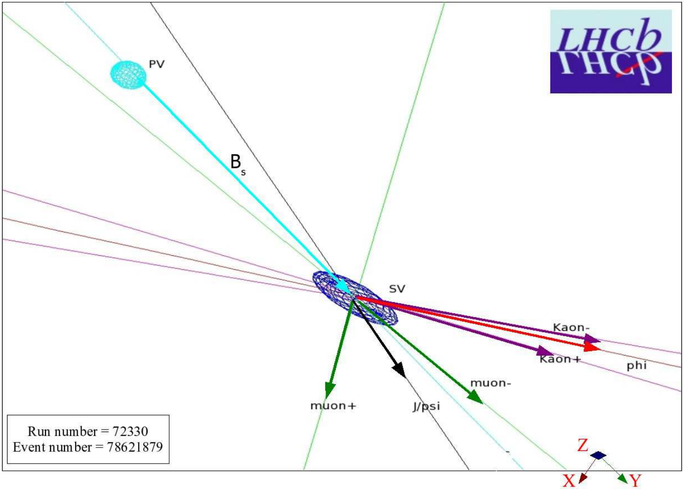


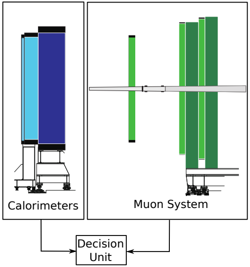
Overview

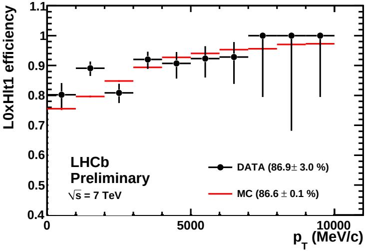
- Trigger and select $B_s \to J/\psi\,\phi$ events
  - Take as large a fraction as possible without lifetime biases.
  - Include lifetime biased triggers for highest yield.
- Measure mass, proper time and angular distributions
- Tag initial flavour
  - Calibrate taggers using control channels $B^0 \to J/\psi\,K^*$, $B^+ \to J/\psi\,K^+$, $B^0 \to D^{*-}\mu^+\nu_\mu$, $B_s \to D_s^-\pi^+$
- Fit $\phi_s^{J/\psi\phi}$
  - Simultaneously fit differential decay rates for tagged and untagged signal and control samples.
  - Depends on 9 physics and $>$ 15 detector parameters.

$$\frac{d^4\Gamma(B_s \to J/\psi\,\phi)}{dt\,d\cos\theta\,d\cos\psi} = f\left(\phi_s, \Delta\Gamma_s, \Gamma_s, \Delta m_s, A_\perp(0), A_\parallel(0), \delta_\perp, \delta_\parallel, M_{B_s}\right)$$

Trigger

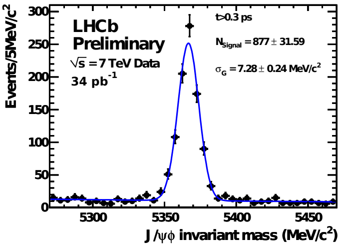
- L0 hardware trigger.
  - Find high P_T leptons or hadrons.
  - Cut on multiplicity.
  - Max $1\mathrm{MHz}$ output rate.
- Hlt1 software trigger.
  - Reconstruct vertices.
  - Find tracks with high IP and/or P_T
- Hlt2 software trigger.
  - Reconstruct full event.
  - Inclusive and exclusive selections.
  - $2\mathrm{kHz}$ output rate.

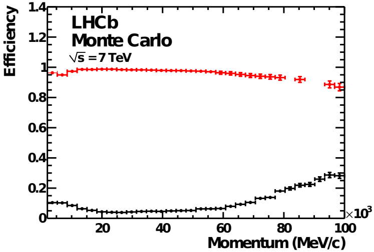




Offline Selection

- Cut based selection, optimised for $S/\sqrt{S+B}$.
- No lifetime biases.
    - No cuts on IP, decay length, etc.
    - Significant prompt background: $B/S \sim 3$
    - Extrapolated yield: $\sim 30\mathrm{k}$ events per fb^{-1}
- Rely on kinematics and PID.
- Full yield available only if lifetime–biased triggers included.





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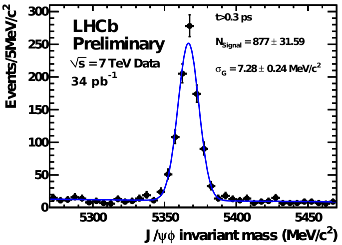
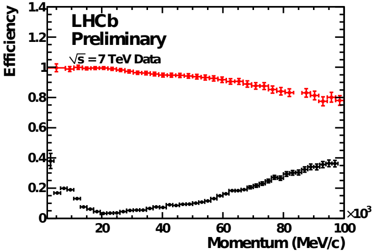
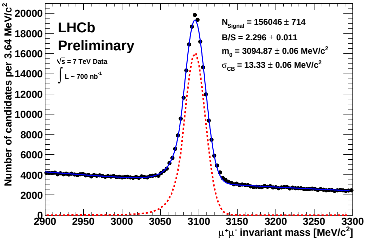
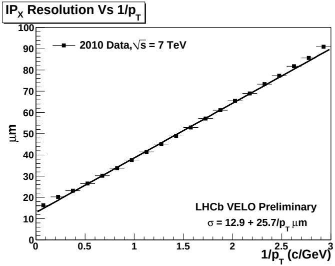




Observables

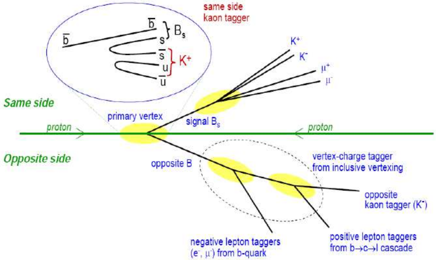
- Excellent tracking performance.
- Excellent mass resolutions.
- Good proper time resolution 38fs MC, $\sim$ 30% worse in data.
- Detector acceptance distorts angular distributions, $\mathcal{O}(8\%)$.
    - Corrected using MC, verified with $B^0 \to J/\psi K^*$.





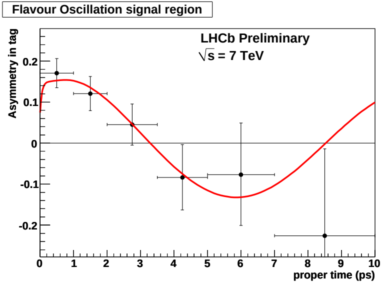
Tagging Introduction

- Initial flavour of B_s mesons must be determined (tagged).
- Use charge of leptons or hadrons from the decay of the other B meson: opposite–side tagging.
- Use charge of kaon produced in the fragmentation: same–side tagging.
- Analysis requires precise knowledge of:
  - Tagging efficiency: ϵ
  - Mistag rate: ω.
- Control channels required.



Tagging in LHCb

- Use self–tagging control channels to calibrate tagging.
- Opposite–side tagging:
    - Fit time evolution in $B^0 \to D^{*-}\mu^+\nu_\mu$.



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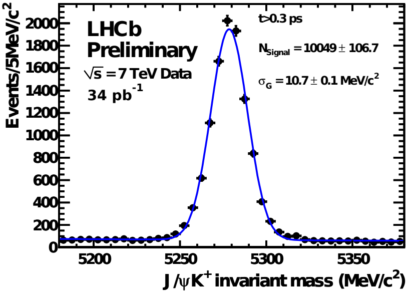

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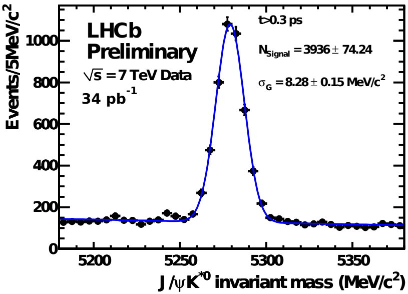

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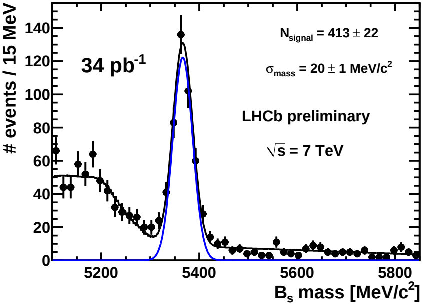
- Same–side tagging:
  - Fit time evolution in $B_s \to D_s^- \pi^+$



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- Same–side tagging:
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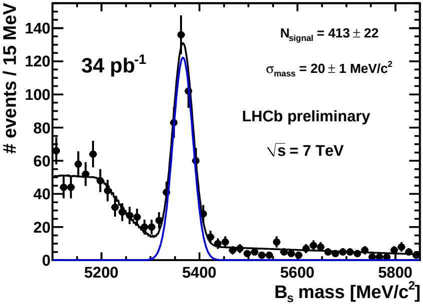
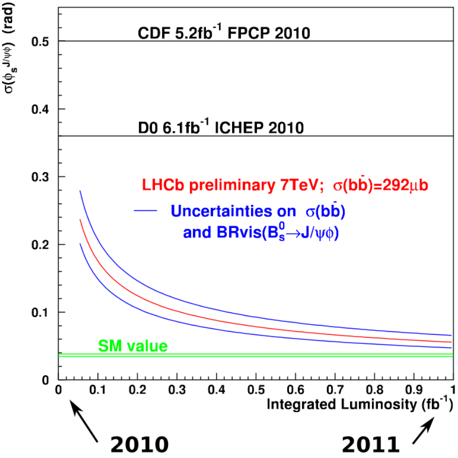
- Tagging optimised on MC and data; MC expectations:



algorithm	$\epsilon(1-2\omega)^2$
all OS	3.32 ± 0.15
SS kaon	2.39 ± 0.10
total	6.23 ± 0.15

Expected Sensitivity

- Sensitivity for a time–dependent, three–angle, flavour–tagged analysis.
- MC expectations used for proper time and tagging.
- $\sim 30\mathrm{k}$ events in $1\mathrm{fb}^{-1}$.
- $\sigma\left(\phi_s^{J/\psi\phi}\right) \sim 0.07\,\mathrm{rad}$.
- From realistic MC, systematic errors at $< 10\%$ level.
- All details in [arXiv:0912:4179v3].



Conclusions and Prospects

- Excellent performance of LHC and LHCb
  - LHC attained it's 2010 target for instantaneous luminosity.
  - Good amount of data on tape.
- So far, $\sim 900\ B_s \to J/\psi\,\phi$ with 34pb^{-1}.
  - Control channels also reconstructed: $B^0 \to J/\psi\,K^*,\ B^+ \to J/\psi\,K^+,\ B^0 \to D^{*-}\mu^+\nu_\mu,\ B_s \to D_s^-\pi^+$
  - Very good mass and proper time resolutions.
  - Background under control.
  - Encouraging tagging performance.
- Analysis well underway and expect 2010 results soon.
- Expect world's best measurement of $\phi_s^{J/\psi\phi}$ for 2011.

$$\sigma\left(\phi_s^{J/\psi\phi}\right) \sim 0.07\,\mathrm{rad} \text{ with } 1\ \text{fb}^{-1}$$