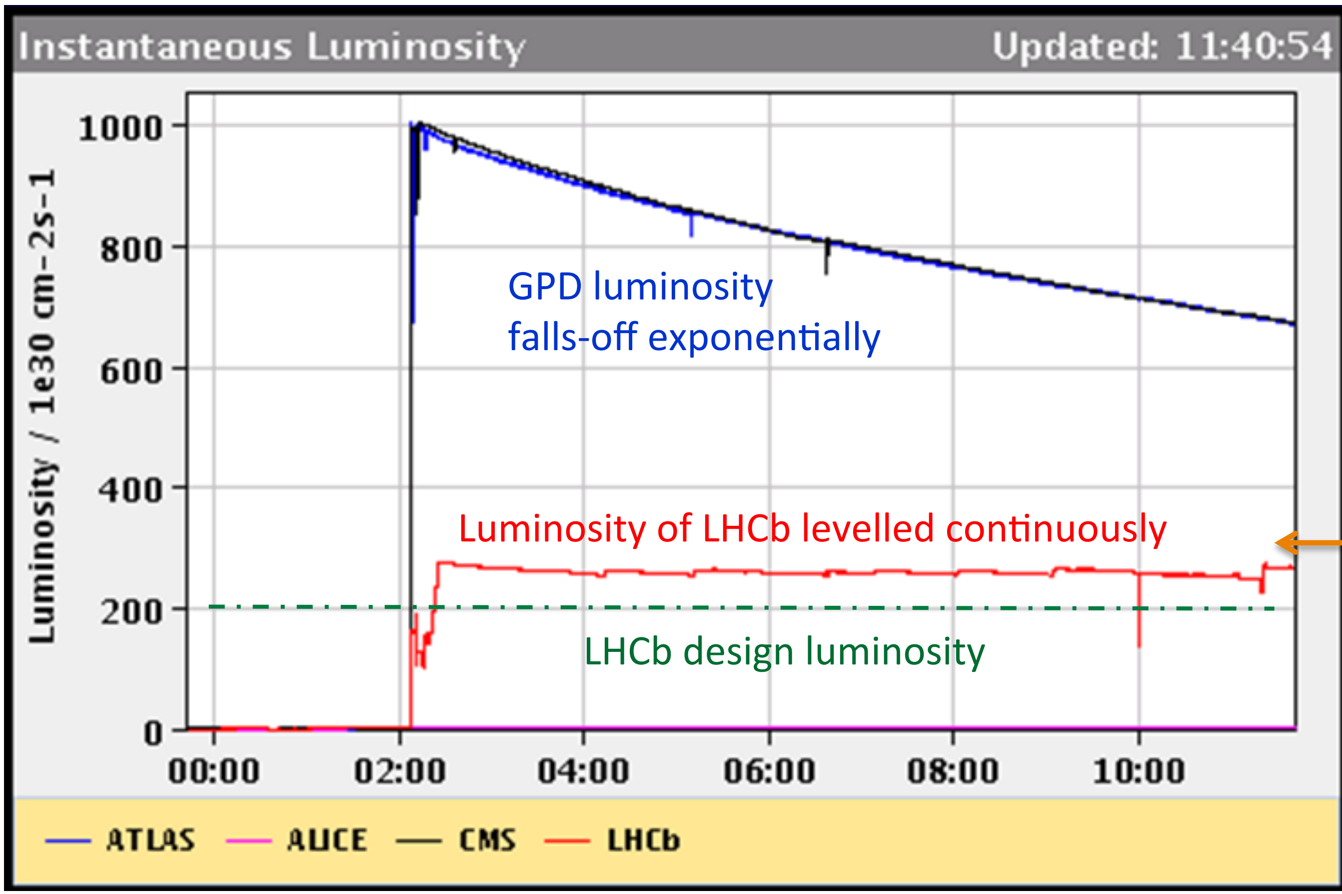
# LHCb Status Report

106th LHCC Meeting

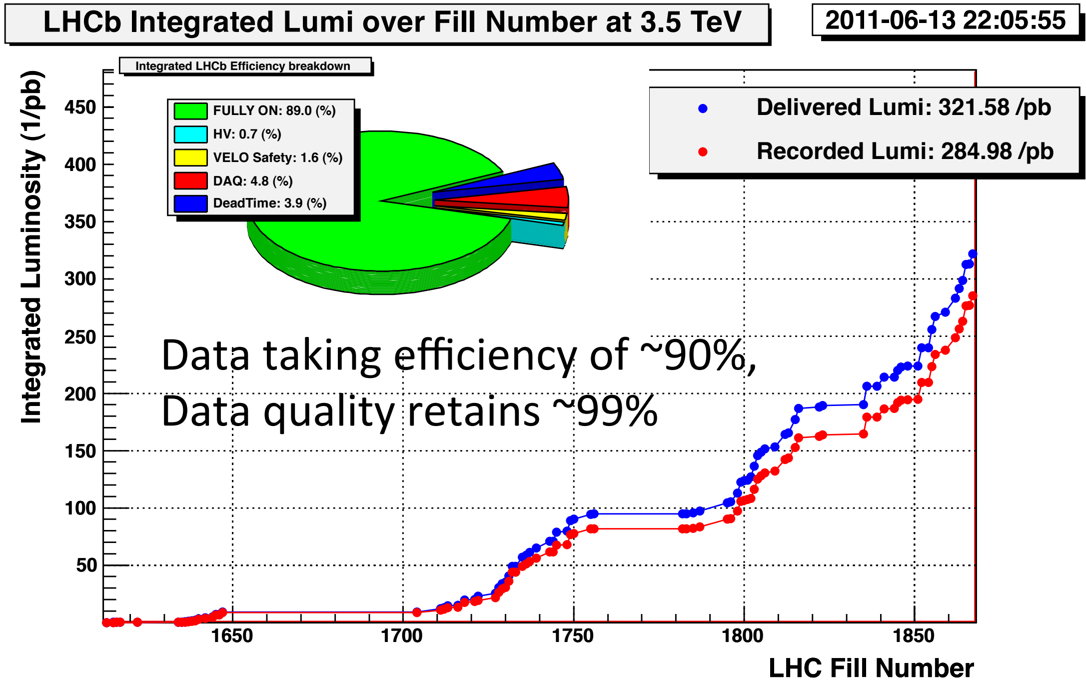
For the LHCb Collaboration, Patrick Robbe, LAL Orsay, 15 June 2011

# Introduction




End of May 2011: LHCb reached stable operation conditions with instantaneous luminosity kept constant at $3x10^{32}$ $cm^{-2}s^{-1}$

# Outline

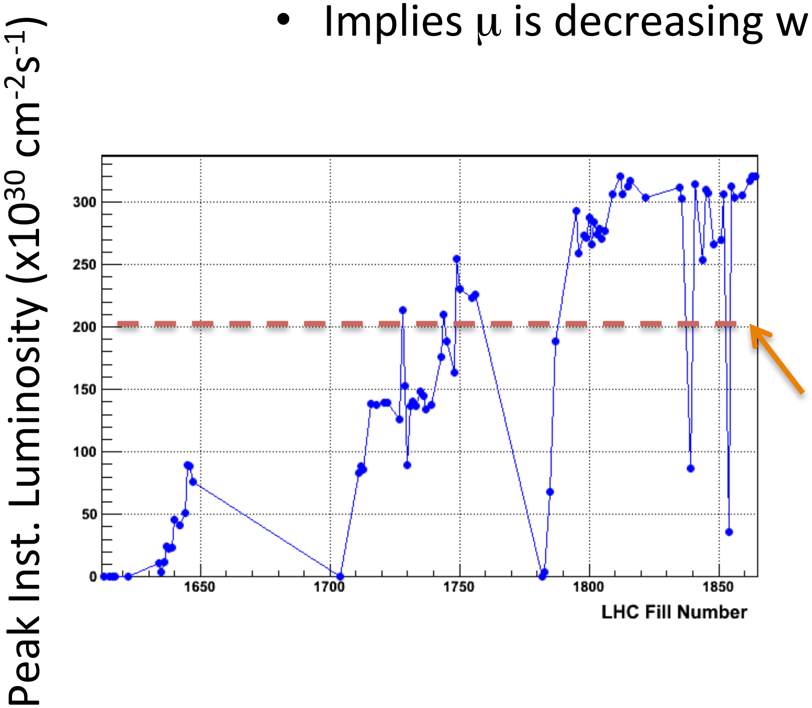



Data taking efficiency of ~90%,
Data quality retains ~99%

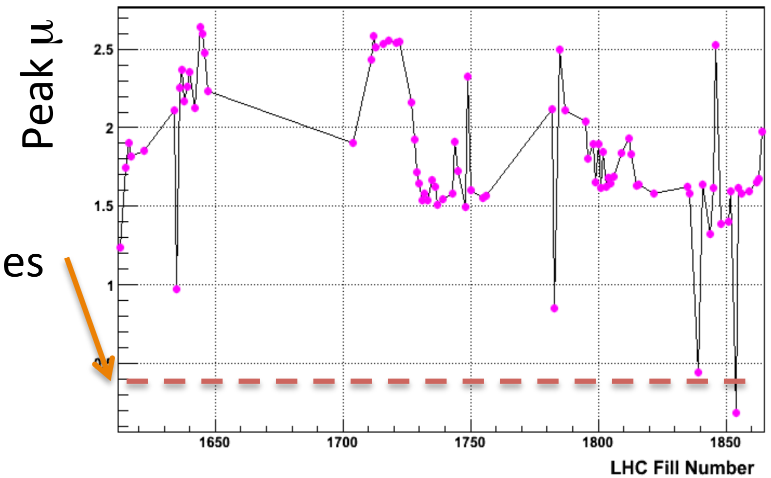
- Almost 300 $pb^{-1}$ recorded
- Operation and detector status
- New physics results with 2010 data (~35$pb^{-1}$):
  - Measurements of production properties in the forward region
  - LHCb first results on Charm Physics
  - CP violation studies
    - LHCb first $\phi_s$ measurement
    - Progress towards $\gamma$ measurement
  - Rare decays

# Operation Strategy

- Luminosity and trigger strategy:
  - Maintain $\mu$ (number of visible interactions per crossing) < 2.5
  - Maintain the instantaneous luminosity ~$3x10^{32}$ $cm^{-2}s^{-1}$, reached on 27 May 2011:
    - Implies $\mu$ is decreasing when increasing the number of bunches.

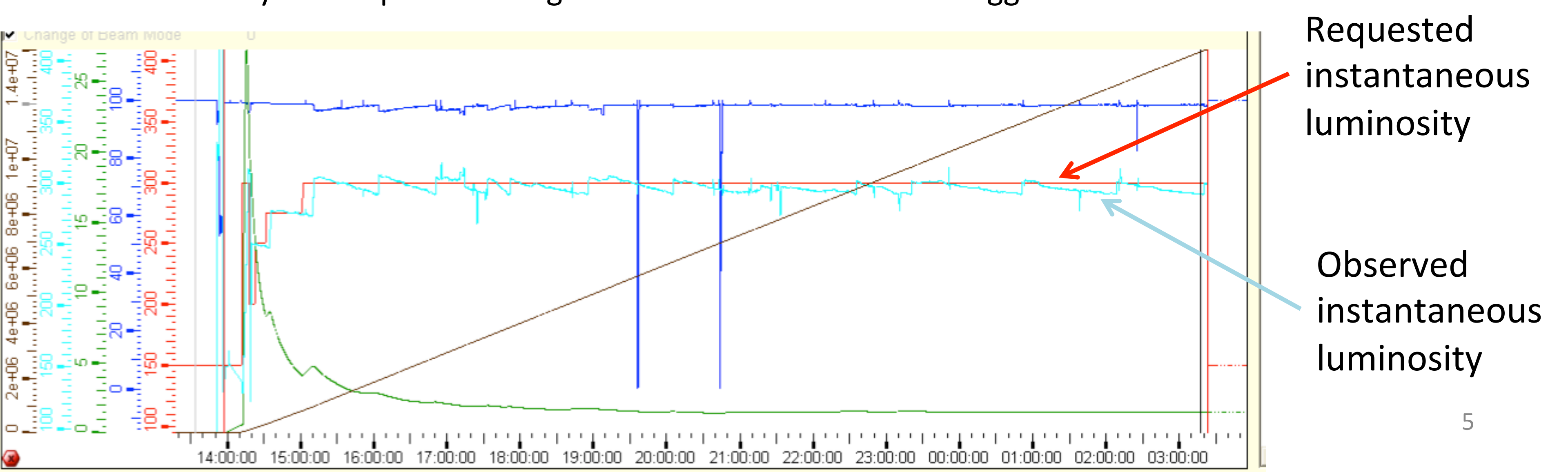



Design values



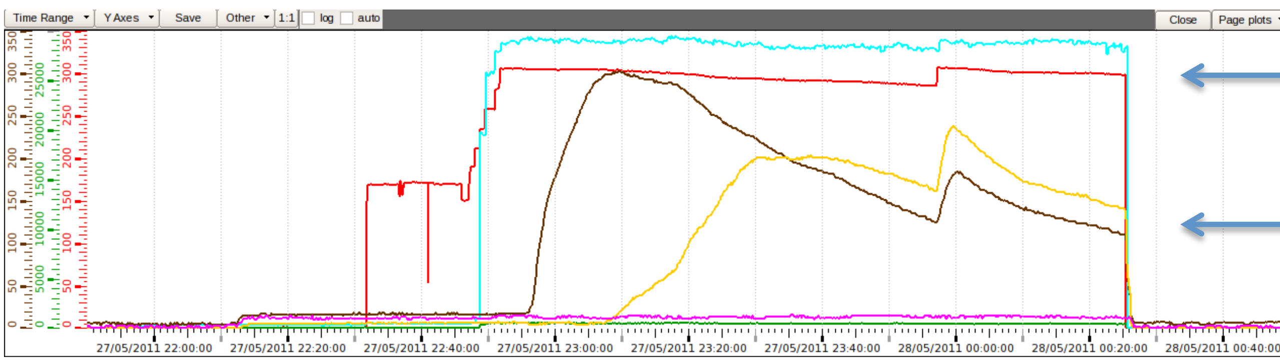
# Luminosity Leveling

- LHC-LHCb Automatic Tool developed to maximize LHCb physics yield, many thanks to LHC team !
  - Maintain luminosity close to the optimal (luminosity efficiency of ~98%)
  - Control luminosity in order to have a stable detector
  - Adjust automatically luminosity, moving the beams relative to each other
- Optimal luminosity (up to now: $3x10^{32}$ $cm^{-2}s^{-1}$) function of:
  - Full event readout rate < 1 MHz
  - $\mu$<2.5 for detector hardware and physics analyses
  - Physics dead-time <5%
  - Physics output to storage 3 kHz + 1 kHz of technical triggers



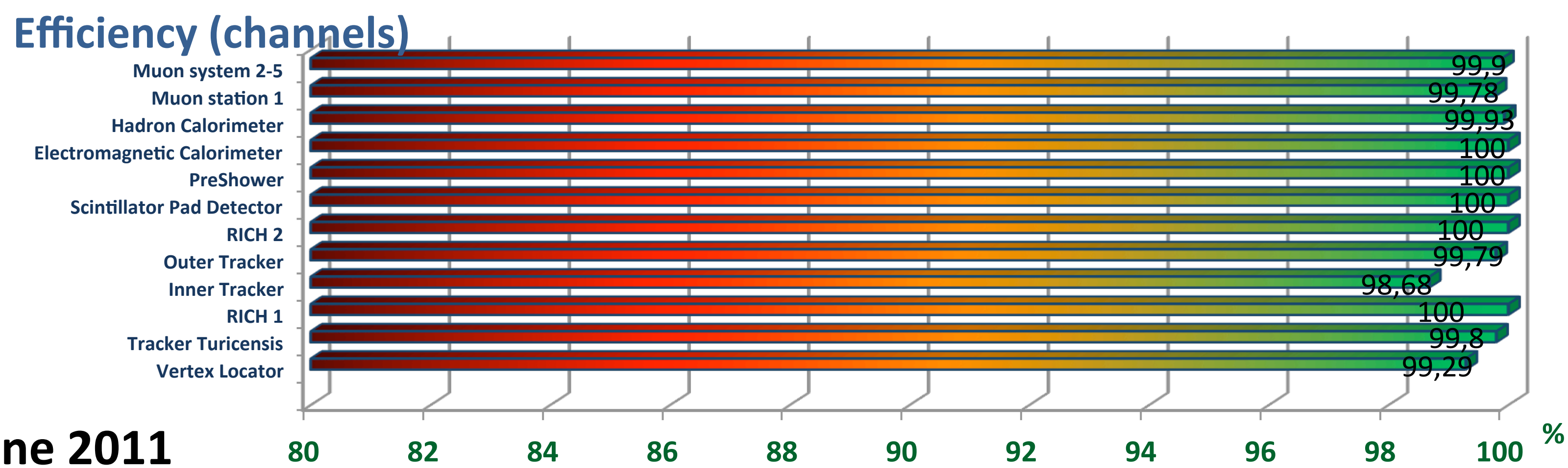
# Detector Status

- Monitor in detail effect of running at luminosity higher than design, and control detector ageing :
  - For example: for Silicon Trackers, increasing luminosity in steps at the beginning of the fill is crucial:




Instantaneous luminosity

Detector currents

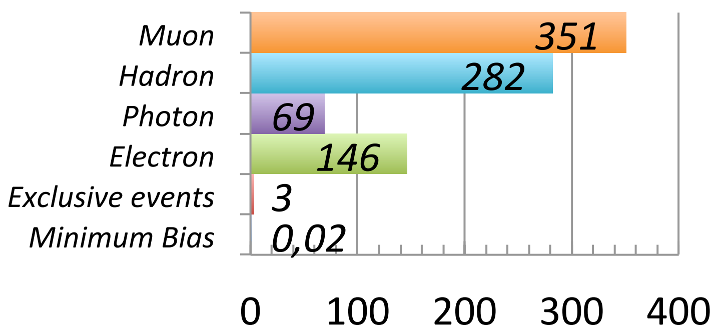



**June 2011**

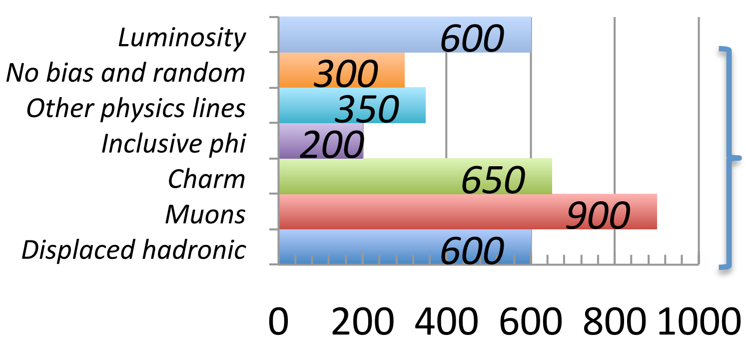
# Trigger

- With 1092 bunches, $3 \times 10^{32}$ $cm^{-2}.s^{-1}$:
  - Visible crossing rate: 8.5 MHz
  - L0 output rate: 650 kHz
  - HLT output rate: 3.6 kHz (3 kHz of physics triggers), written on tape
  - HLT Farm CPU busy at 80%

**L0 Output Rate (kHz, non exclusive)**

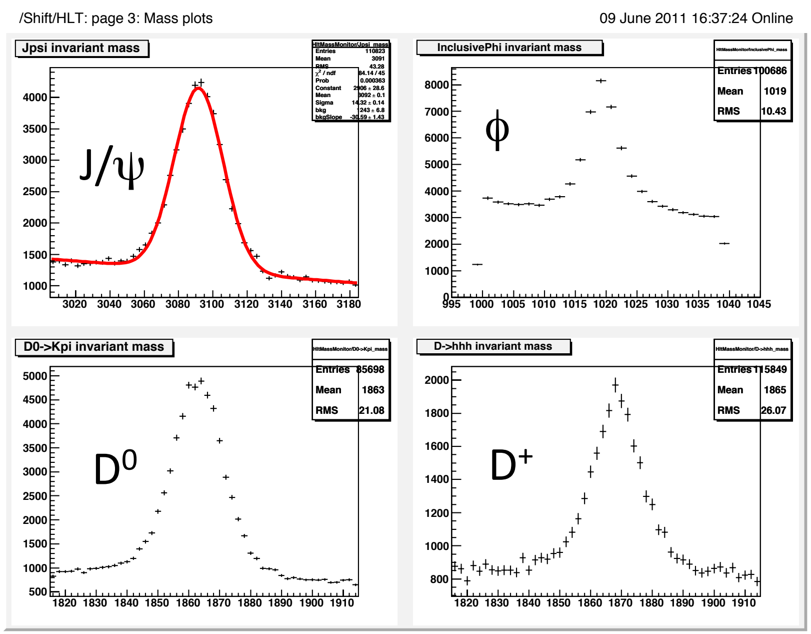



**HLT Output Rate (Hz)**




Physics: 3 kHz

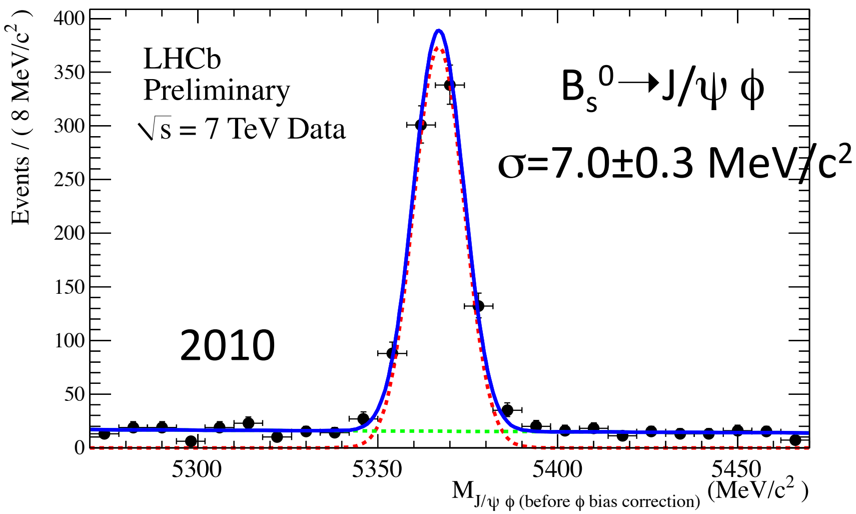
*Mass peaks seen online in the control room, at the output of the trigger.*



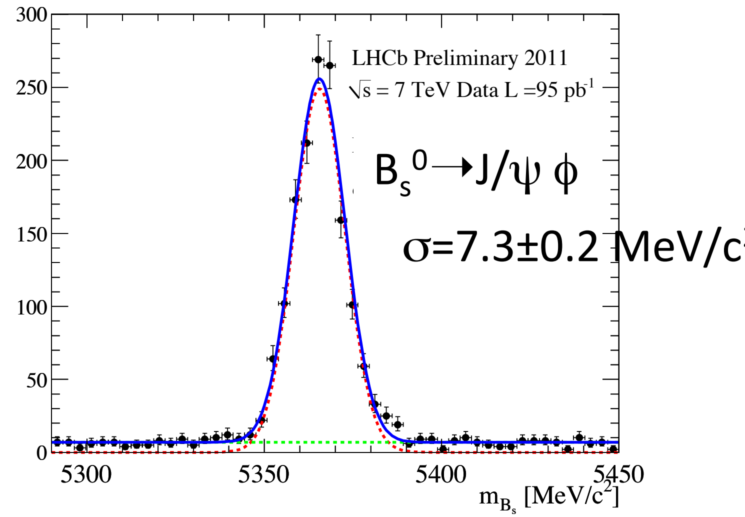
# Mass Measurements

- Preliminary mass measurements of B species are the world's best measurements (except for $B_c$), thanks to good control of systematics (alignment, detector material, field)

*LHCb-CONF-2011-027*




Similar performances with 2011 data

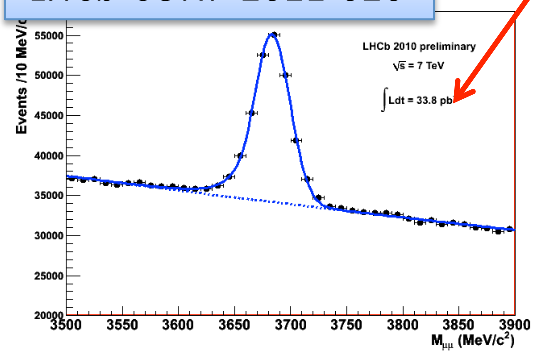


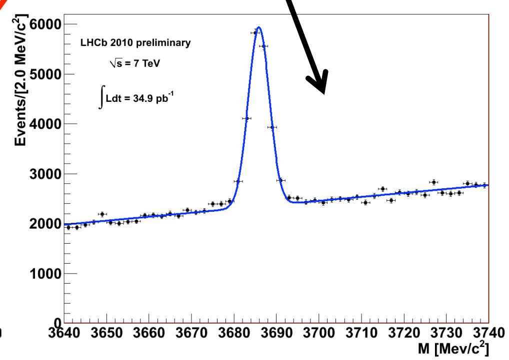

| Channel | | LHCb mass [MeV/$c^2$] | PDG [MeV/$c^2$] |
|---|---|---|---|
| $M(B^+ \to J/\psi K^+)$ | = | $5279.27 \pm 0.11\,(\text{stat}) \pm 0.20\,(\text{syst})$ | $5279.17 \pm 0.29$ |
| $M(B^0 \to J/\psi K^{*0})$ | = | $5279.54 \pm 0.15\,(\text{stat}) \pm 0.16\,(\text{syst})$ | $5279.50 \pm 0.30$ |
| $M(B^0 \to J/\psi K^0_S)$ | = | $5279.61 \pm 0.29\,(\text{stat}) \pm 0.20\,(\text{syst})$ | $5279.50 \pm 0.30$ |
| $M(B^0_s \to J/\psi \phi)$ | = | $5366.60 \pm 0.28\,(\text{stat}) \pm 0.21\,(\text{syst})$ | $5366.30 \pm 0.60$ |
| $M(\Lambda_b \to J/\psi \Lambda)$ | = | $5619.49 \pm 0.70\,(\text{stat}) \pm 0.19\,(\text{syst})$ | $5620.2 \pm 1.6$ |
| $M(B^+_c \to J/\psi \pi^+)$ | = | $6268.0 \pm 4.0\,(\text{stat}) \pm 0.6\,(\text{syst})$ | $6277 \pm 6$ |

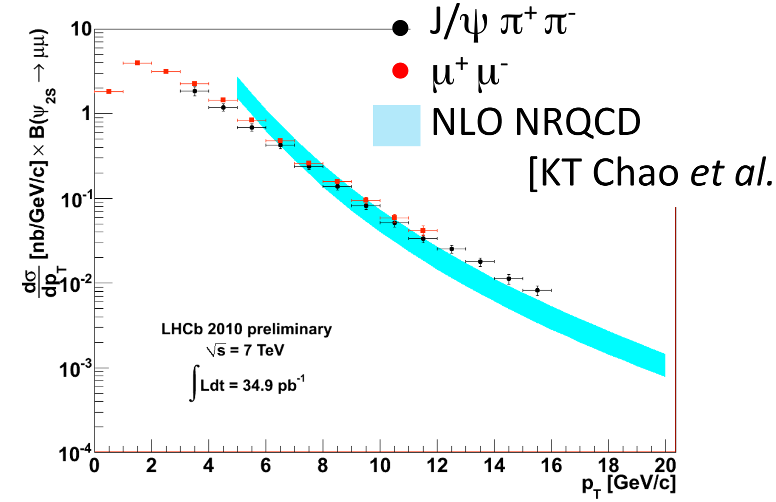
# Production: quarkonium

- Further cross-section measurements in addition to $J/\psi$ and $\Upsilon(1S)$, to test with more observables quarkonium production models.
- Inclusive $\psi(2S) \rightarrow \mu^+\mu^-$ and $J/\psi\pi^+\pi^-$

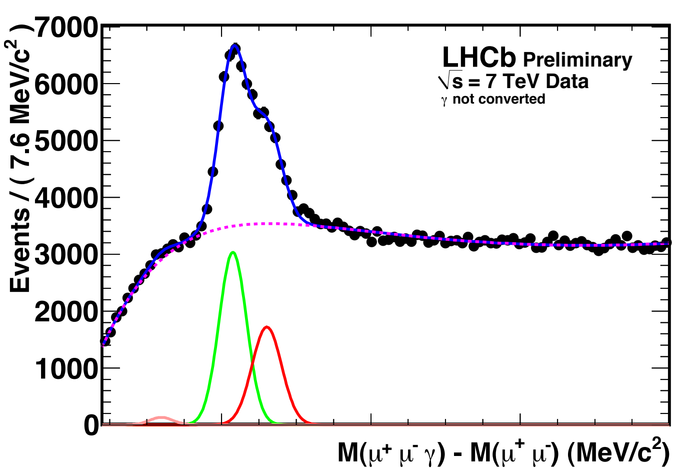
*LHCb-CONF-2011-026*

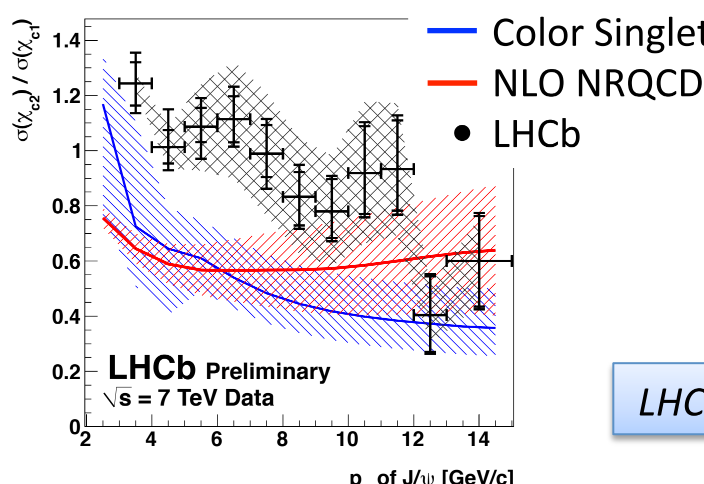



- Prompt $\chi_{c(1,2)} \rightarrow J/\psi\ \gamma$, with photon reconstructed in ECAL

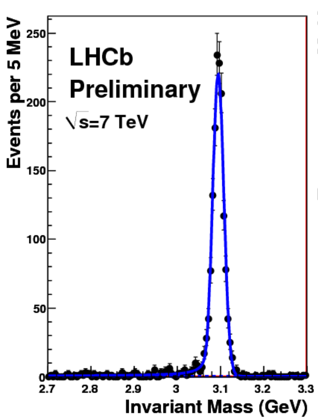


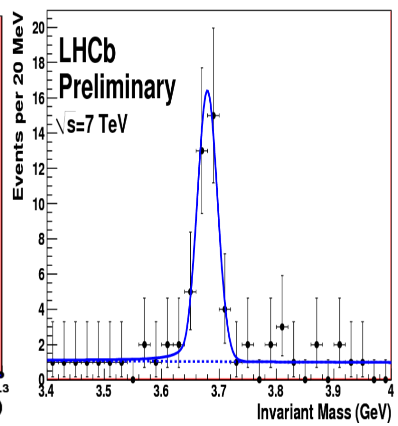

*LHCb-CONF-2011-020*

# Production: exclusive charmonium

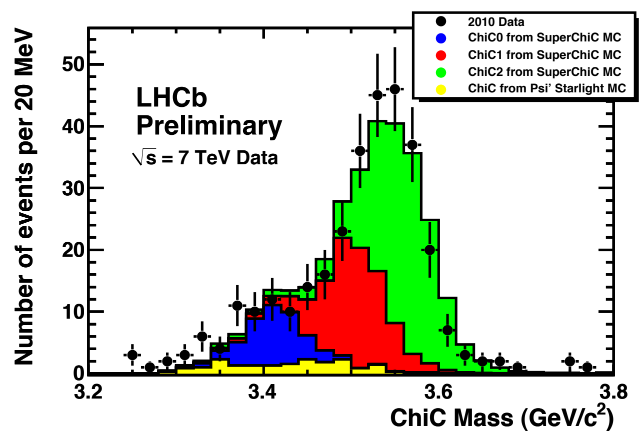
- Production of 1 charmonium state and nothing else: possible if one colour-less object is exchanged.
- Thanks to VELO, capability also to detect backward charged tracks.
- Study of pomeron and odderon in a clean environment.



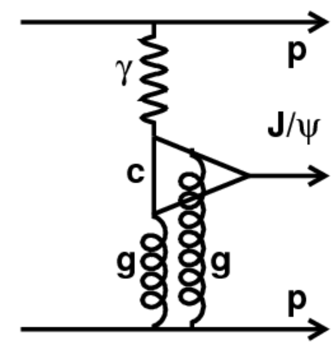
J/ψ



ψ (2S)



$\chi_{c0,1,2}$



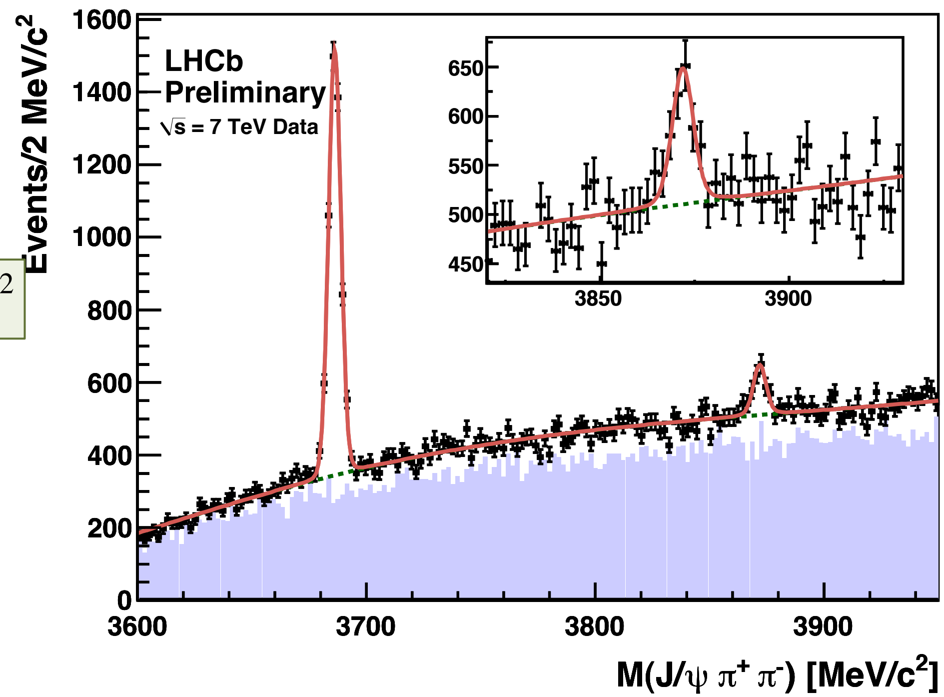

$$\sigma(J/\psi \rightarrow \mu^+\mu^-, 2 < \eta_{\mu^+}, \eta_{\mu^-} < 4.5) = 474 \pm 12 \pm 51 \pm 92\,\text{pb}$$

*LHCb-CONF-2011-020*

# Production: exotic states

- Huge dimuon sample allows searching for and studying charmonium/bottomonium like exotic states.
- For example, measurement of the mass of the X(3872). The comparison of its mass with $m(D^{*0})+m(D^0)$ gives information about its nature. Will be improved with 2011 data.

$$M(X(3872)) = 3871.96 \pm 0.46 \pm 0.10\,\mathrm{MeV}/c^2$$



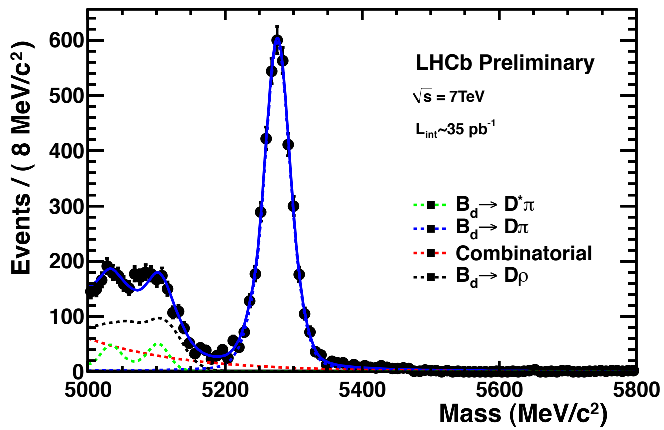

*LHCb-CONF-2011-026*

$\psi(2S) \rightarrow J/\psi\, \pi^+\pi^-$ and $X(3872) \rightarrow J/\psi\, \pi^+\pi^-$, with $J/\psi \rightarrow \mu^+\mu^-$

# Production: *B* fragmentation, $f_s/f_d$

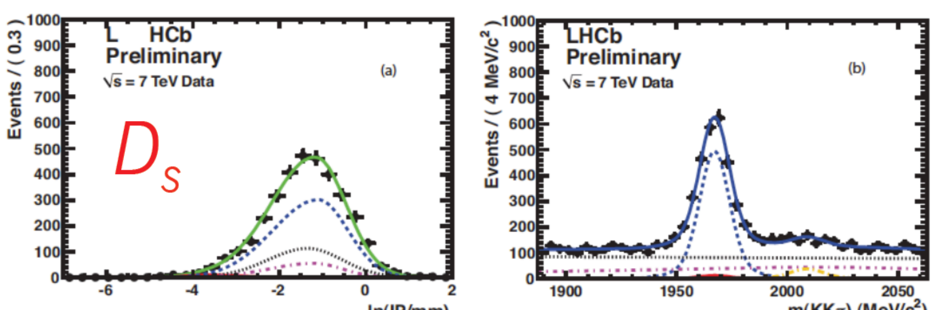
- $f_{u,d,s,baryon}$=probability for a b quark to hadronize in a $B^+$, $B^0$, $B_s$ or b-baryon.
- $f_d/f_s$ measured from ratios of $B^0$ and $B_s$ reconstructed in:
  - <u>Hadronic decay modes</u>: $B_s^0 \rightarrow D_s^- \pi^+$ compared to $B^0 \rightarrow D^- \pi^+$ or $B^0 \rightarrow D^- K^+$

*LHCb-CONF-2011-013*




$$\frac{f_s}{f_d} = 0.245 \pm 0.017 \pm 0.018 \pm 0.018$$

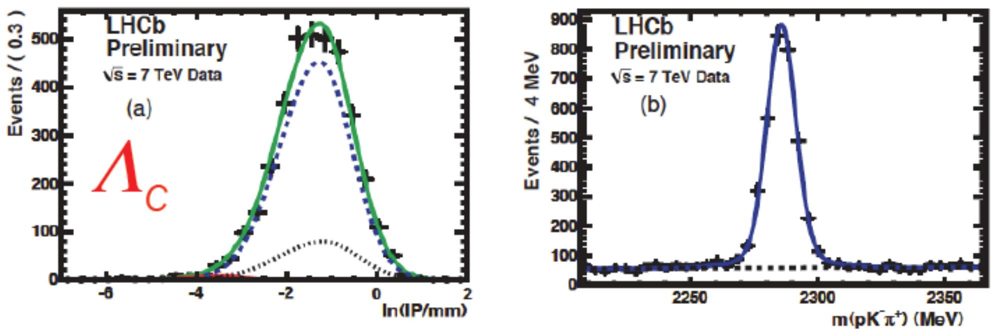
  - <u>Semi-leptonic decay modes</u>: $B \rightarrow (D^+, D_s^+)\mu\nu X$



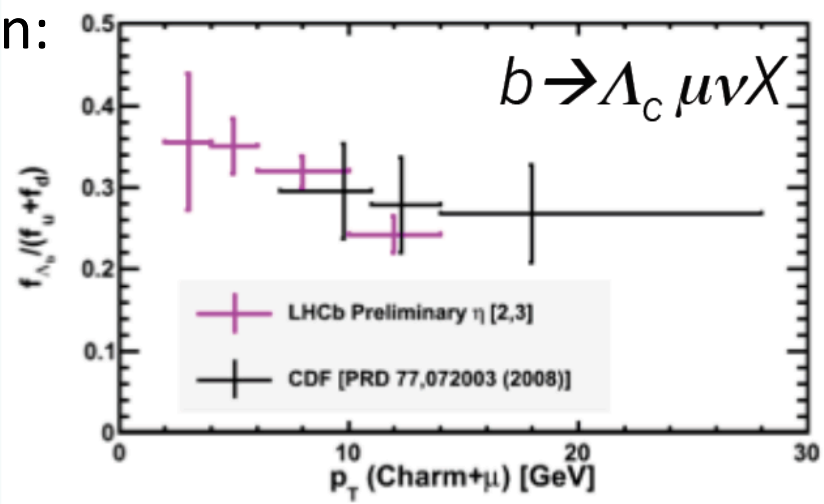

$$\frac{f_s}{f_d} = 0.272 \pm 0.008^{+0.024}_{-0.022}$$

# Production: $B$ fragmentation, $f_{\Lambda b}$

- $f_{\Lambda b}/(f_u+f_d)$ from semi-leptonic decays




- b-baryon fraction observed to depend on B $p_T$: this could explain the discrepancy between b-baryon fractions measured at LEP and Tevatron:

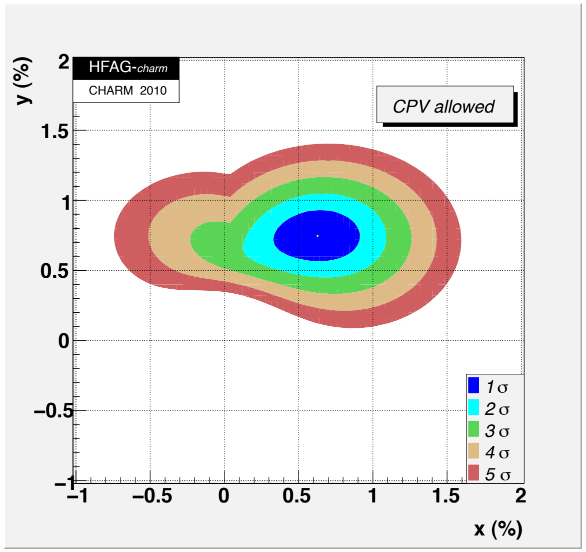



$$\frac{f_{\Lambda_b}}{f_u + f_d} = (0.401 \pm 0.019 \pm 0.106) - (0.0120 \pm 0.0025 \pm 0.0012) \times p_T / \mathrm{GeV}$$

# Charm

LHCb-CONF-2010-013

- Large charm cross-section at LHC ($\sigma$ = 6.10±0.93 mb) can be exploited to perform very precise mixing and CP violation measurements in the charm sector.




$$x = \frac{\Delta m}{\Gamma}$$

$$y = \frac{\Delta\Gamma}{2\Gamma}$$

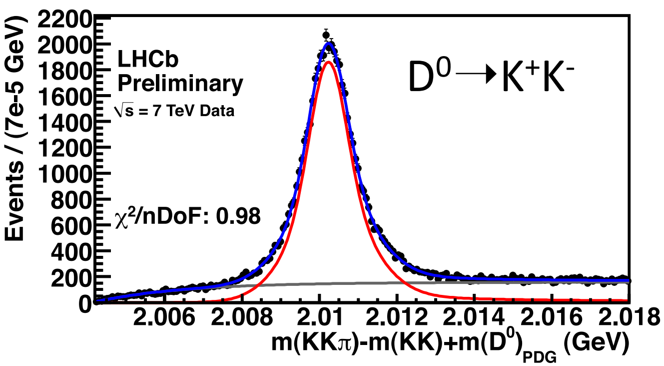
- At the output of the L0 trigger, half of the events contain a charm: need to have in HLT exclusive selections of the interesting decay modes: ~1 kHz output rate of pure charm events.

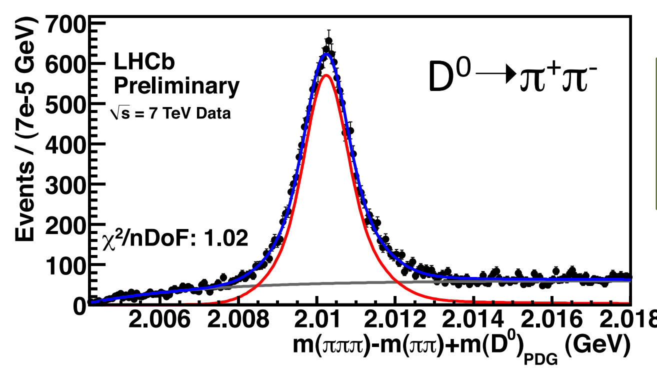
# Charm: time integrated CP asymmetry

- Search for direct CP violation, expected to give asymmetries of $10^{-3}$ in Standard Model and could be enhanced to $10^{-2}$ by New Physics.
- Measure asymmetries of CP modes $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$, from a $D^{*+}$ decay (tagged).

$$A_{RAW} = \frac{N(D^{*+} \rightarrow D^0\pi^+) - N(D^{*-} \rightarrow \bar{D}^0\pi^-)}{N(D^{*+} \rightarrow D^0\pi^+) + N(D^{*-} \rightarrow \bar{D}^0\pi^-)} = A_{CP} + A_{Detection} + A_{Production}$$

- Compute differences of CP asymmetries where production and detection asymmetries cancel.




$$A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.28 \pm 0.70 \pm 0.25)\%$$

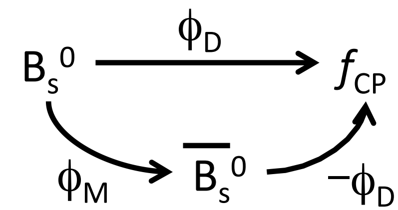
Error of 0.1% with $1\text{fb}^{-1}$

- Measure also production asymmetry of $D^0$ in *pp* collisions at 7 TeV:

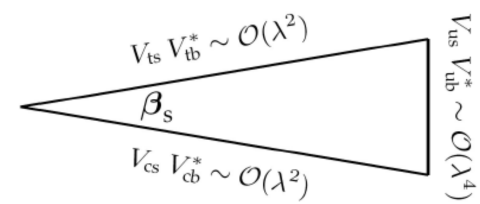
$$A_{Production}(D^0) = (-1.08 \pm 0.32 \pm 0.12)\%$$

*LHCb-CONF-2011-026*

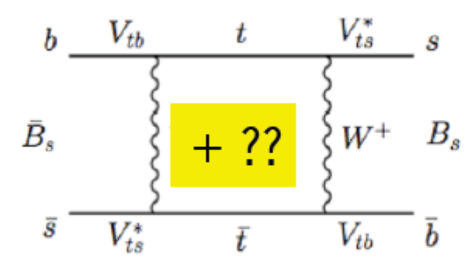
# CP Violation in $B_s$ decays : $\phi_S$




- Study the CP violation in interference between decay and mixing in $B_s$ decays.
- Use $B_s^0 \to J/\psi\ (\mu^+\mu^-)\ \phi\ (K^+K^-)$ decays:
  - CP violating phase $\phi_S = \phi_M - 2\phi_D$
  - In the Standard Model, $\phi_S$ is well determined: $\phi_S = -2\beta_S = -0.0363 \pm 0.0017$ rad, up to penguin diagram phase contributions ($10^{-4} - 10^{-3}$).



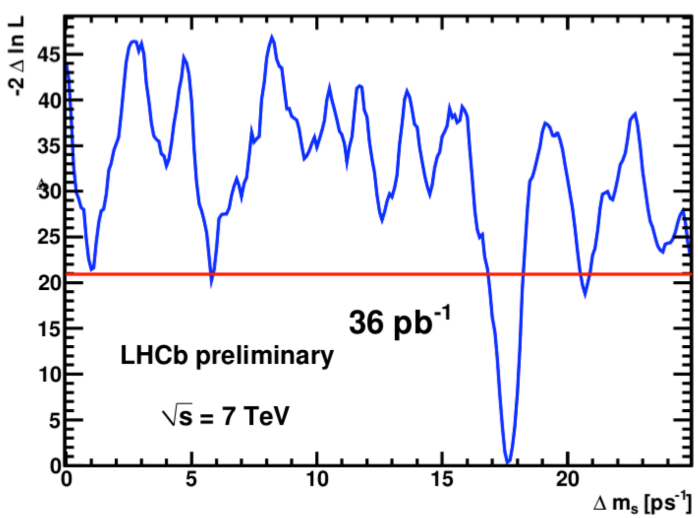

- The mixing phase, $\phi_M \approx 0$ in Standard Model can be modified by New Physics and enhance the measured $\phi_S$.

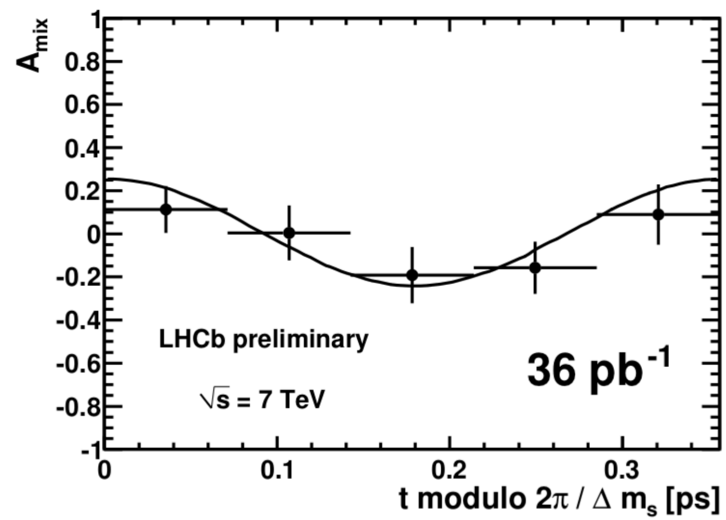



- Since the decay is P $\to$ VV, the final state is superposition of states with different CP value: the measurement requires a complex ***tagged***, ***time-dependent***, ***angular analysis***.

# Tagged: measurement of B mixing

- Flavour of B hadron at production is tagged by:
  - Opposite side: sign of $\mu$, e, K and charge of tracks from secondary vertex
  - Same side: sign of accompanying $\pi$ ($B^0$, $B^+$) and K ($B_s^0$) [not used yet]
- Performance calibrated on data ($B^+ \to J/\psi K^+$).
- For $B_s^0 \to J/\psi\ \phi$, using only opposite side algorithms:
  - $\varepsilon_{tag} = (17.6 \pm 1.4)\%$, $\omega = (32 \pm 2)\%$, $\varepsilon_{tag}(1-2\omega)^2 = (2.2 \pm 0.5)\%$
- $\Delta m_s$ measured using $B_s^0 \to D_s^- \pi^+$ and $B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$ (1300 events)



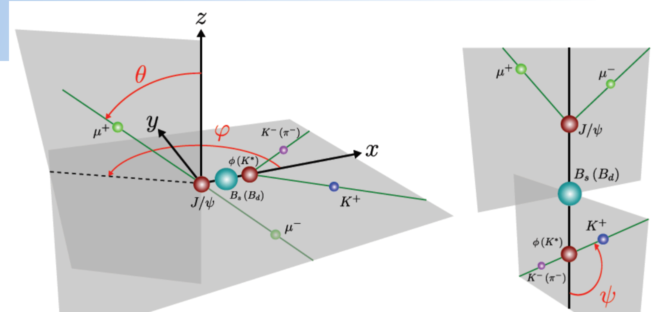




LHCb-CONF-2011-005

$$\Delta m_s = 17.63 \pm 0.11 \pm 0.04\,\mathrm{ps}^{-1}$$

Single world's best measurement

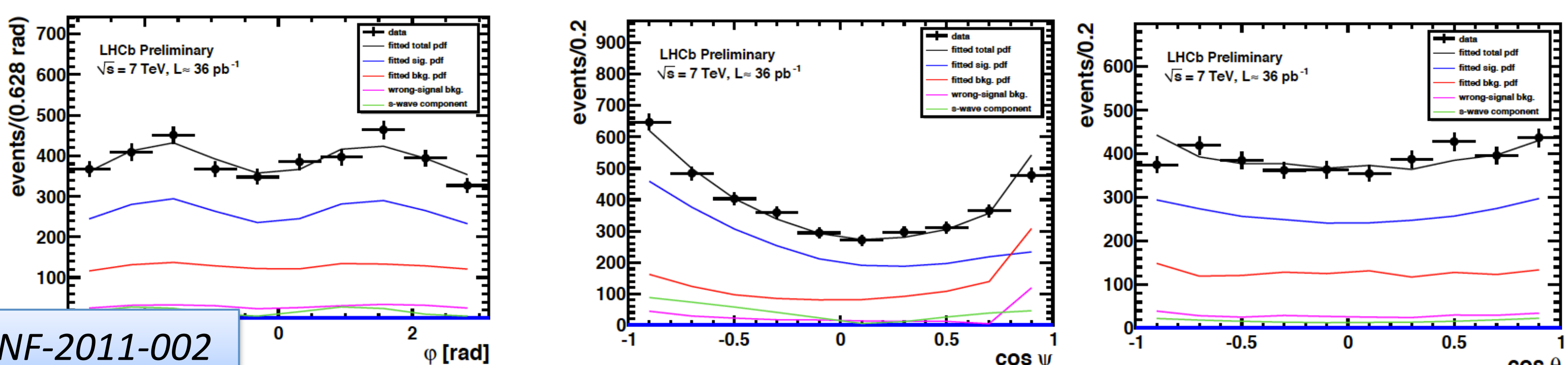
# Angular analysis: $B^0 \rightarrow J/\psi\ K^{*0}$ polarization amplitudes




*Decay angles in the transversity basis*

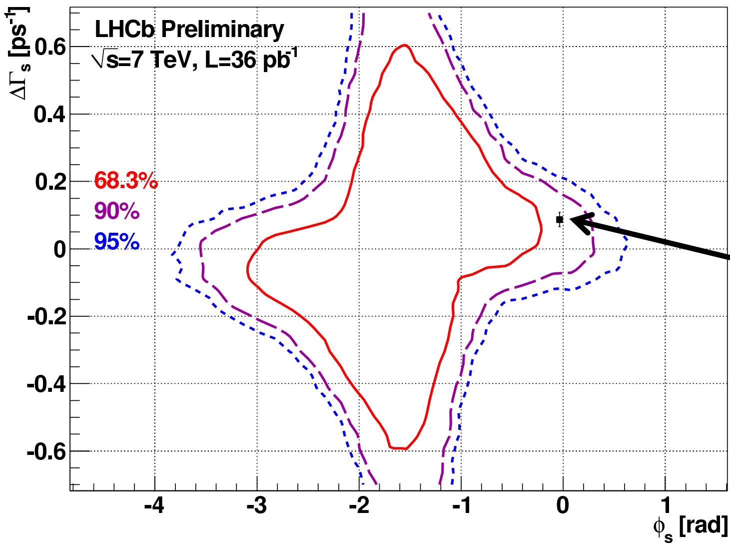
- Similar angular analysis required: simultaneous fit to m, t, $\phi$, $\psi$, $\theta$.
- Acceptances are not flat as a function of the decay angles: corrections (~5%) taken from simulation.
- Results obtained with 2600 signal events, in good agreement with BaBar measurement, but not yet competitive. Validates understanding of angular acceptance and fit.

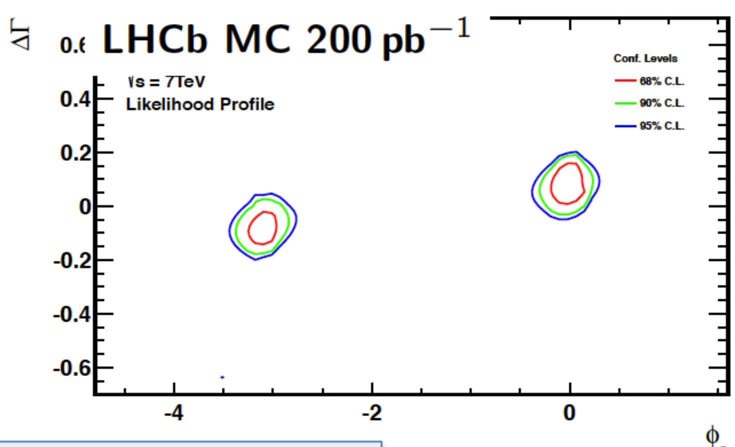
| Parameter | LHCb prelim. | BaBar PRD 76, 031002 |
|---|---|---|
| $\lvert A_{\parallel}(0)\rvert^2$ | $0.252 \pm 0.020_{stat.} \pm 0.016_{syst.}$ | $0.211 \pm 0.010_{stat.} \pm 0.006_{syst.}$ |
| $\lvert A_{\perp}(0)\rvert^2$ | $0.178 \pm 0.022_{stat.} \pm 0.017_{syst.}$ | $0.233 \pm 0.010_{stat.} \pm 0.005_{syst.}$ |
| $\delta_{\parallel}$ | $-2.87 \pm 0.11_{stat.} \pm 0.10_{syst.}$ | $-2.93 \pm 0.08_{stat.} \pm 0.04_{syst.}$ |
| $\delta_{\perp}$ | $3.02 \pm 0.10_{stat.} \pm 0.07_{syst.}$ | $2.91 \pm 0.05_{stat.} \pm 0.03_{syst.}$ |




LHCb-CONF-2011-002

# $B_s^0 \rightarrow J/\psi\ \phi$: measurement of $\phi_s$




LHCb-CONF-2011-006

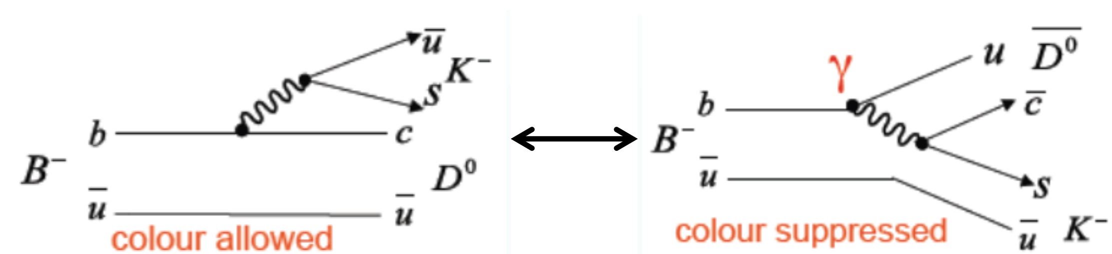
- 757±28 signal events, not enough to make a point estimate of $\phi_s$.
- Confidence Level contours in $\phi_s - \Delta\Gamma_s$ plane (statistical errors only, but systematics are small)
- Standard Model *p*-value: 22%

- With the same analysis performances, expect sensitivity of 0.13 rad on $\phi_s$ with 1 $fb^{-1}$.
- Improvements to the analysis expected in 2011 (use of same side tagging, use $B_s^0 \rightarrow J/\psi\ f_0$, …) will increase this sensitivity.
- World's best measurement in 2011.

| | LHCb 36 $pb^{-1}$ | CDF 5.2 $fb^{-1}$ |
|---|---|---|
| $B_s \rightarrow J/\psi\,\phi$ | 836 | 6500 |
| Proper time resolution | 50 fs | 100 fs |
| OS tagging power | $2.2 \pm 0.5\%$ | $1.2 \pm 0.2\%$ |
| SS tagging power | work ongoing | $3.5 \pm 1.4\%$ |

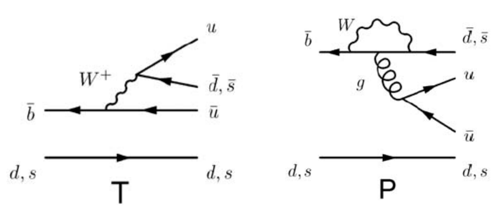
# CP Violation in B decays : $\gamma$ angle

- $\gamma$ is the Unitarity Triangle angle measured with largest uncertainty so far, direct measurement still less precise than the Standard Model prediction.
- Experimentally measured using:
  - Interferences at tree level between $B^+$ and $B^-$ decays to a final state common to $D^0$ and $\overline{D^0}$, and a K: <u>not affected by New Physics</u>.




- $D^0 \rightarrow K^+K^-$, $\pi^+\pi^-$ [GLW]
- $D^0 \rightarrow K^-\pi^+$, $D^0 \rightarrow K^+\pi^-$ [ADS]
- $D^0 \rightarrow K_s^0\pi^+\pi^-$, $K_s^0K^+K^-$ [GGSZ]

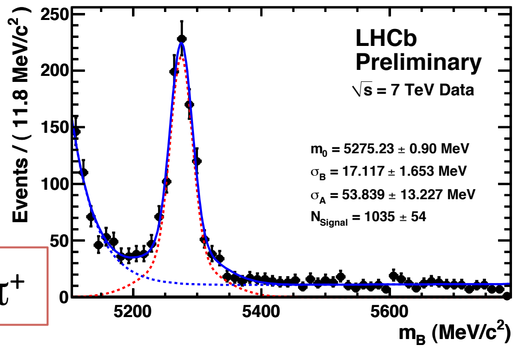
  - Interferences between tree diagrams and penguin diagrams of charmless B decays: very sensitive to New Physics in loops



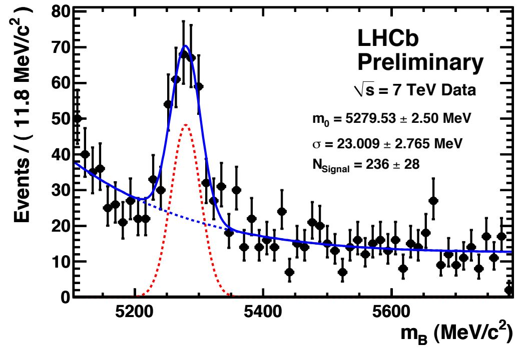

- Full time dependent analysis will take time, but interesting results already from time-integrated rates and lifetimes.

# Path to $\gamma$ : $B \rightarrow D^0(hh)h$ signals

- Not enough statistics for $\gamma$ measurement, but first clean signals of $B \rightarrow D^0(hh)h$ reconstructed with $35pb^{-1}$, with expected yields.
- GLW

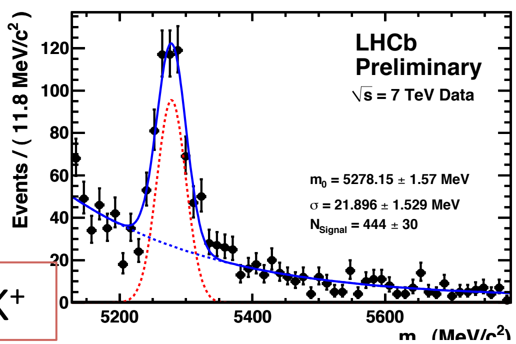



$B^+ \rightarrow D^0(K^+K^-)\pi^+$




$B^+ \rightarrow D^0(\pi^+\pi^-)\pi^+$

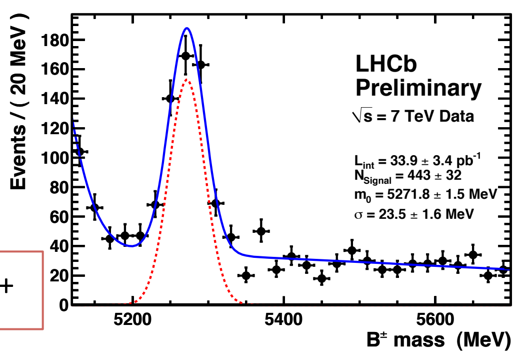
- ADS



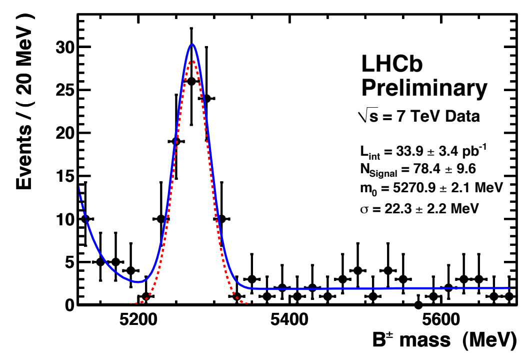

$B^+ \rightarrow D^0(K^-\pi^+)K^+$

Expect sensitivity of 5° on $\gamma$ with 2 $fb^{-1}$

- GGSZ




$B^+ \rightarrow D^0(K_s^0\pi^+\pi^-)\pi^+$

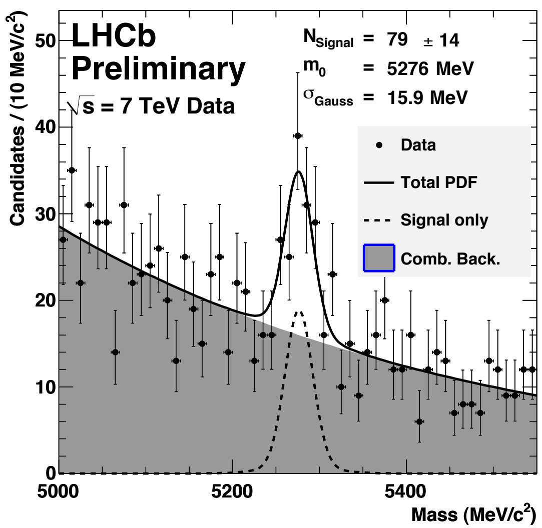



$B^+ \rightarrow D^0(K_s^0K^+K^-)\pi^+$

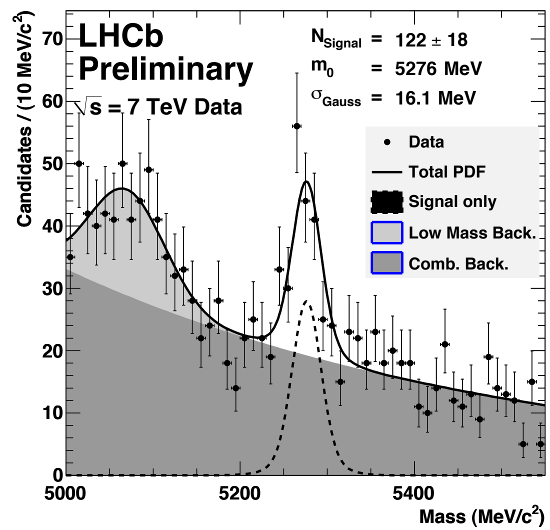
# γ angle from trees

*LHCb-CONF-2011-024*

- Can also use higher multiplicity decays.
- First observation of the Cabibbo-suppressed decays:




$B^0 \to D^- K^+ \pi^+ \pi^-$




$B^+ \to \overline{D}^0 K^+ \pi^+ \pi^-$

$$\frac{B(B^0 \to D^- K^+ \pi^+ \pi^-)}{B(B^0 \to D^- \pi^+ \pi^+ \pi^-)} = (5.2 \pm 0.9 \pm 0.5) \times 10^{-2}$$

$$\frac{B(B^+ \to \bar{D}^0 K^+ \pi^+ \pi^-)}{B(B^+ \to \bar{D}^0 \pi^+ \pi^+ \pi^-)} = (9.6 \pm 1.5 \pm 0.8) \times 10^{-2}$$

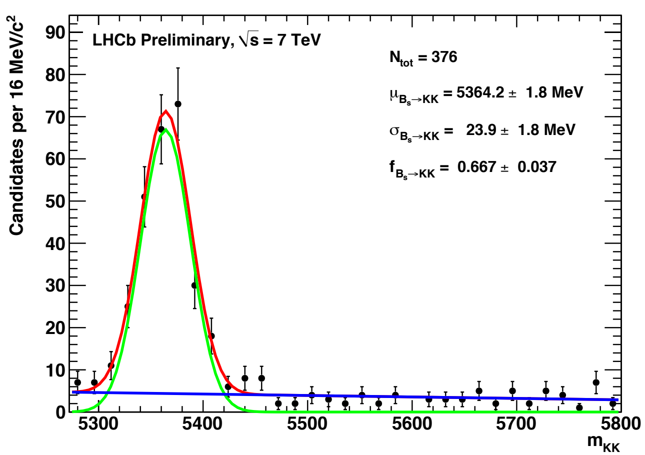
- Up to 6 tracks in the final state: good tracking and trigger performances.

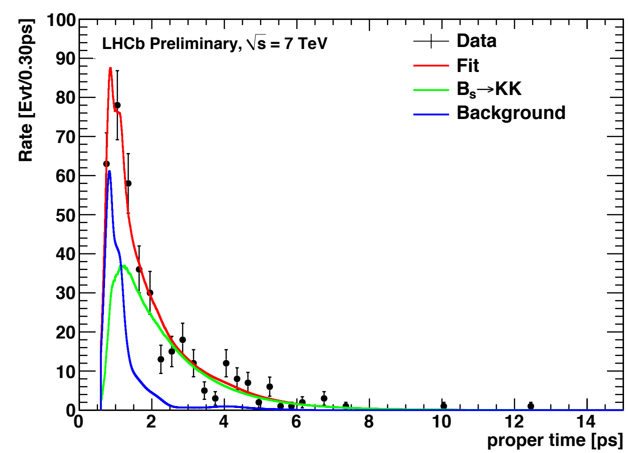
# $B_s^0 \to K^+ K^-$ Lifetime

- Decay width difference between the heavy ($B_{sH}^0$) and light ($B_{sL}^0$) states is sensitive to New Physics.

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H = \Delta\Gamma_s^{SM} \cos(\phi^{NP})$$

- A single exponential fit to the $B_s^0$ proper time distribution gives an effective lifetime measurement, $B_s^0$ is almost a pure light state.



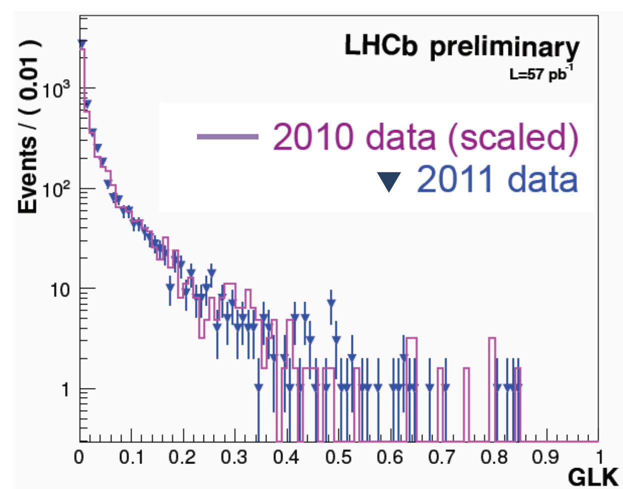

- With 250 events, already world's best measurement.

$$\tau(B_s^0 \to K^+K^-) = 1.440 \pm 0.096 \pm 0.010\,\text{ps}$$

*LHCb-CONF-2011-018*

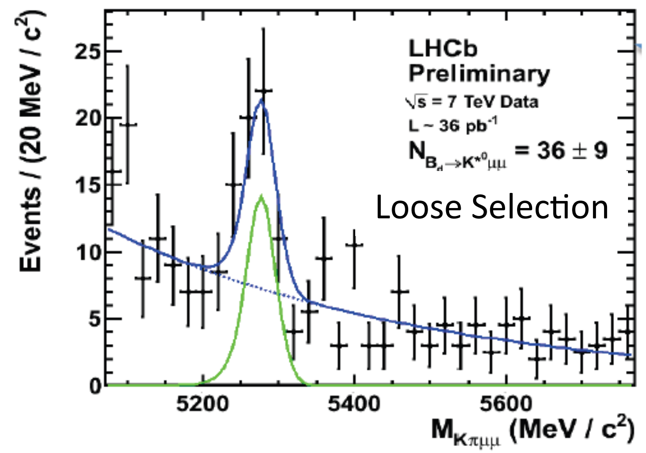
# B rare decays

- Search and study of rare decays which could be affected by New Physics through heavy particles in diagrams.
- Discovery potential of New Physics also at large scale or provides constraints on New Physics parameter space.
- First LHCb limits on $B_{s,d}^0 \rightarrow \mu^+\mu^-$ (37 $pb^{-1}$): *Physics Letters B 699 (2011) 330-340*
  - $B(B_s^0 \rightarrow \mu^+\mu^-) < 4.3\ (5.6) \times 10^{-8}$ @ 90% (95%) CL
  - $B(B_d^0 \rightarrow \mu^+\mu^-) < 1.2\ (1.5) \times 10^{-8}$ @ 90% (95%) CL
  - With 2011 data, explore $B(B_s^0 \rightarrow \mu^+\mu^-)$~5-10 x $10^{-9}$ (SM: ~3 x $10^{-9}$)
- Comparison of background measured in mass sidebands, in 2010 and 2011 data.
- Update of $B_{s,d}^0 \rightarrow \mu^+\mu^-$ expected during the summer.

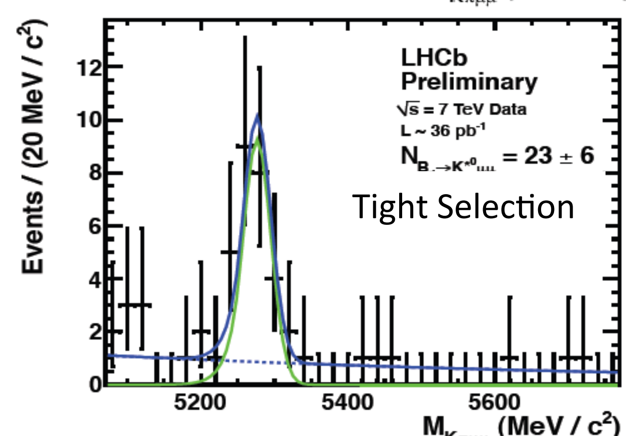


# $B^0 \to K^{*0}\mu^+\mu^-$

- Promising reconstructed $B^0 \to K^{*0}\mu^+\mu^-$ signal to study forward-backward asymmetry, $A_{FB}$, *ie* the number of forward and backward emitted positive muons in the $\mu\mu$ rest frame.
- Expect 1000 events in 1 $fb^{-1}$ with loose selection (B/S=1)



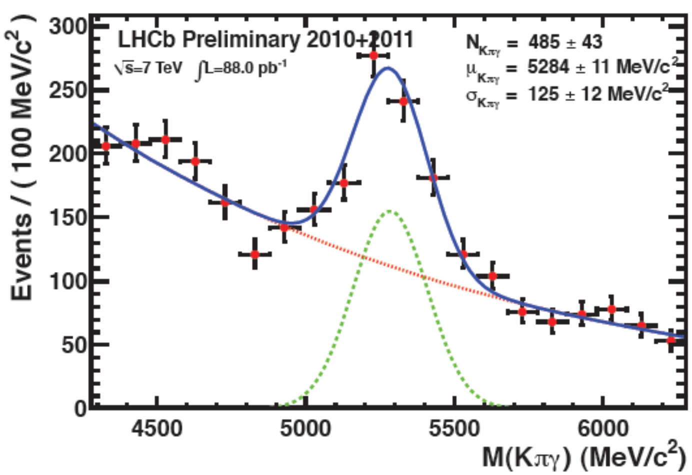

- or 600 events with purer selection (B/S=0.2)



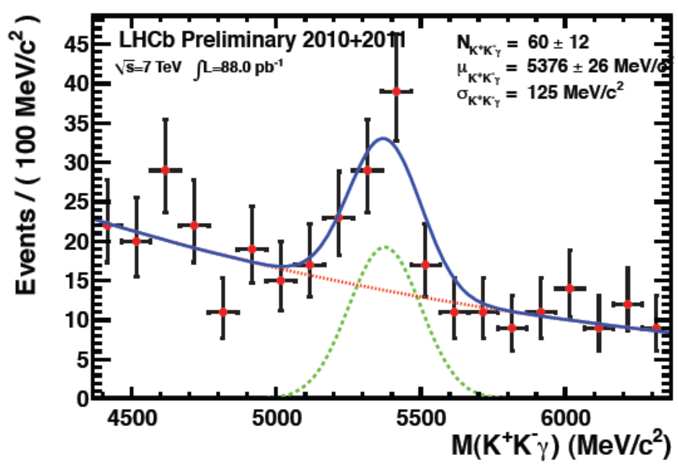

- Preliminary results on $A_{FB}$ expected during the summer.

# Radiative Decays

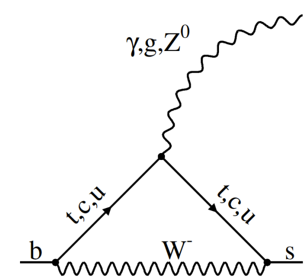
- Measure photon polarization (through angular analysis) and extract: $\left|\frac{A(B \to \Phi\lambda_R)}{A(B \to \Phi\lambda_L)}\right|$
- Rely on photon trigger and photon reconstruction in the Electromagnetic Calorimeter.
- Improve existing measurement of $B(B_s^0 \to \phi\gamma)/B(B^0 \to K^{*0}\gamma)$ during the summer.




$B^0 \to K^{*0}\gamma$, expect 6000 events in 1 $fb^{-1}$

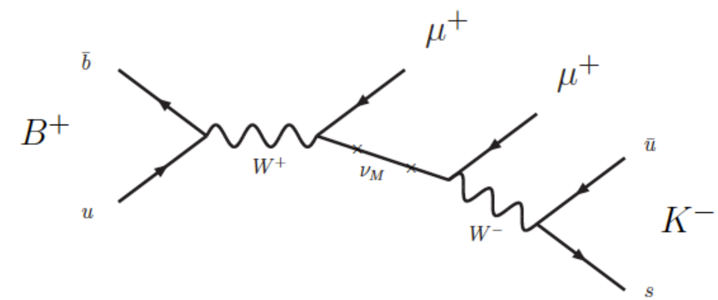



$B_s^0 \to \phi\gamma$, expect 600 events in 1 $fb^{-1}$



# Search for $B^+ \rightarrow h^- \mu^+ \mu^+$

- Search for $B^+ \rightarrow K^- \mu^+ \mu^+$ and $B^+ \rightarrow \pi^- \mu^+ \mu^+$ with 2010 data.
- Decay forbidden in Standard Model, but can be mediated by Majorana neutrinos.



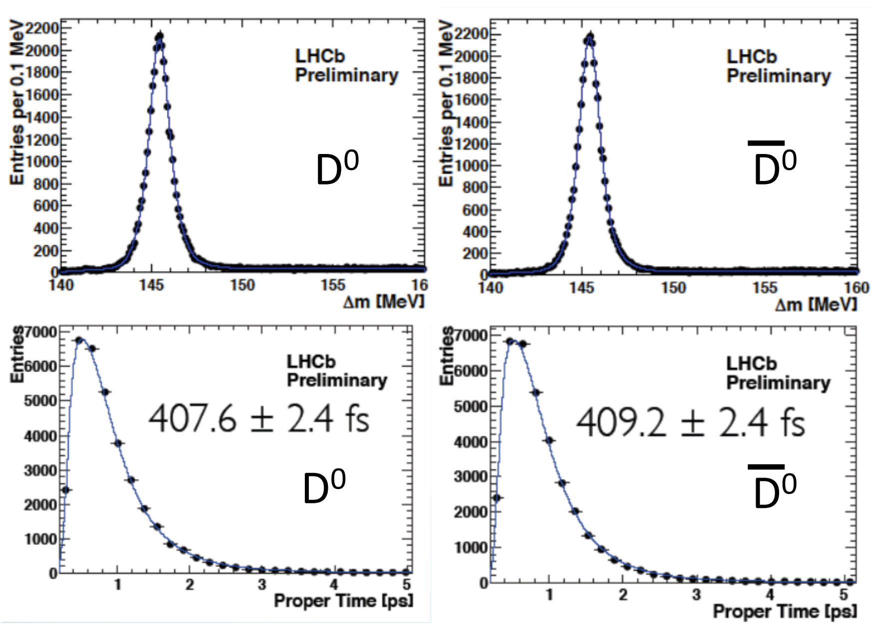

- < 0.3 (0.1) background events expected in $\pi\mu\mu$ ($K\mu\mu$) mode
- Zero events observed in both signal regions and sidebands
- Limits:
  - $B(B^+ \rightarrow K^- \mu^+ \mu^+) < 4.3 \times 10^{-8}$ @ 90% C.L.
  - $B(B^+ \rightarrow \pi^- \mu^+ \mu^+) < 4.5 \times 10^{-8}$ @ 90% C.L.
  - Factor 40 (30) improvement compared to best limits (CLEO)

# Conclusions

- LHCb collecting data now at a constant luminosity 50% above design luminosity, in stable conditions: thanks to LHC team !
- ~300 $pb^{-1}$ for the summer conferences, ~1 $fb^{-1}$ for the end of 2011 are realistic goals
- Very exciting measurements accessible with these large data sets:
  - $\phi_s$ with $B_s^0 \to J/\psi\ \phi$
  - $B_s^0 \to \mu^+ \mu^-$
  - $B^0 \to K^{*0} \mu^+ \mu^-$
  - Competitive $\gamma$ measurements
- LHCb also active with many other analyses not presented here:
  - Minimum bias or weak boson production measurements in the forward region,
  - Spectroscopy of excited states,
  - New decay modes observations

# Charm: time dependent CP asymmetry

- Future measurements at LHCb with 2011 data:
  - $D^0$ mixing: $y_{CP} = \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to K^-K^+)} - 1$ (to be measured at 5$\sigma$)
  - CP violation: $A_\Gamma = \frac{\tau(\bar{D}^0 \to K^+K^-) - \tau(D^0 \to K^+K^-)}{\tau(\bar{D}^0 \to K^+K^-) + \tau(D^0 \to K^+K^-)}$ to be measured with $10^{-3}$ precision
- Control measurement of "$A_\Gamma$" with tagged $D^0 \to K^-\pi^+$:

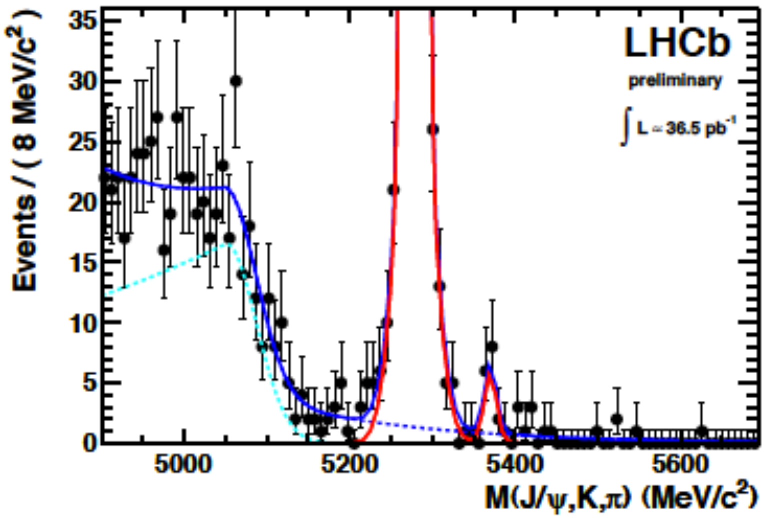



$$A_\Gamma^{K\pi,eff} = (-2 \pm 4).10^{-3}$$

No bias seen, now proceed with physics measurements

# $B_s^0 \rightarrow J/\psi\ \overline{K}^{*0}$

LHCb-CONF-2011-025



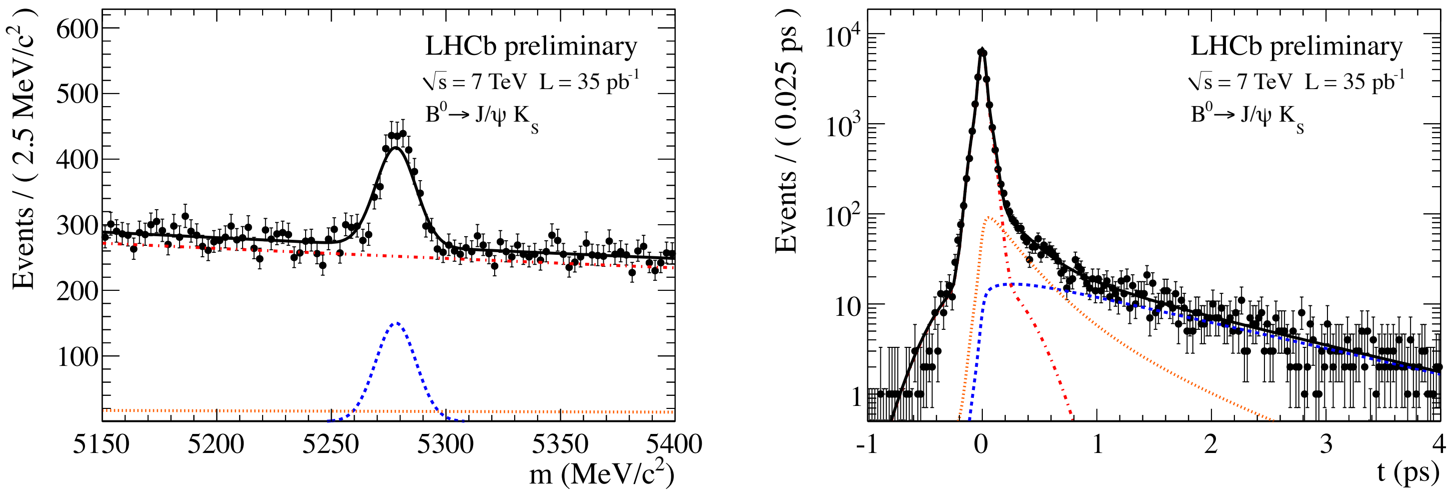

- Will allow to control penguin contamination in $\phi_s$ measurement with $B_s^0 \rightarrow J/\psi\ \phi$.

$$B(B_s^0 \rightarrow J/\psi \overline{K}^{*0}) = (3.5^{+1.1}_{-1.0} \pm 0.9) \times 10^{-5}$$

# Time dependent CPV: measurement of sin2β

- Using 1330 events reconstructed in $B^0 \rightarrow J/\psi\ K_S{}^0$, recorded with decay time unbiased and biased triggers

*LHCb-CONF-2011-004*




- Tagging with opposite and same sign: $\varepsilon(1-2\omega)^2 \approx 2.8\%$
- Proper time resolution: ≈50 fs
- Sine term of asymmetry (sin2β if no direct CP violation nor CP violation in $B^0$ mixing):

$$S_{J/\psi K_S^0} = 0.53^{+0.28}_{-0.29} \pm 0.05$$

- Measurement far from begin competitive (yet !) with B factories, but exercises time dependent CP violation measurements in LHCb.