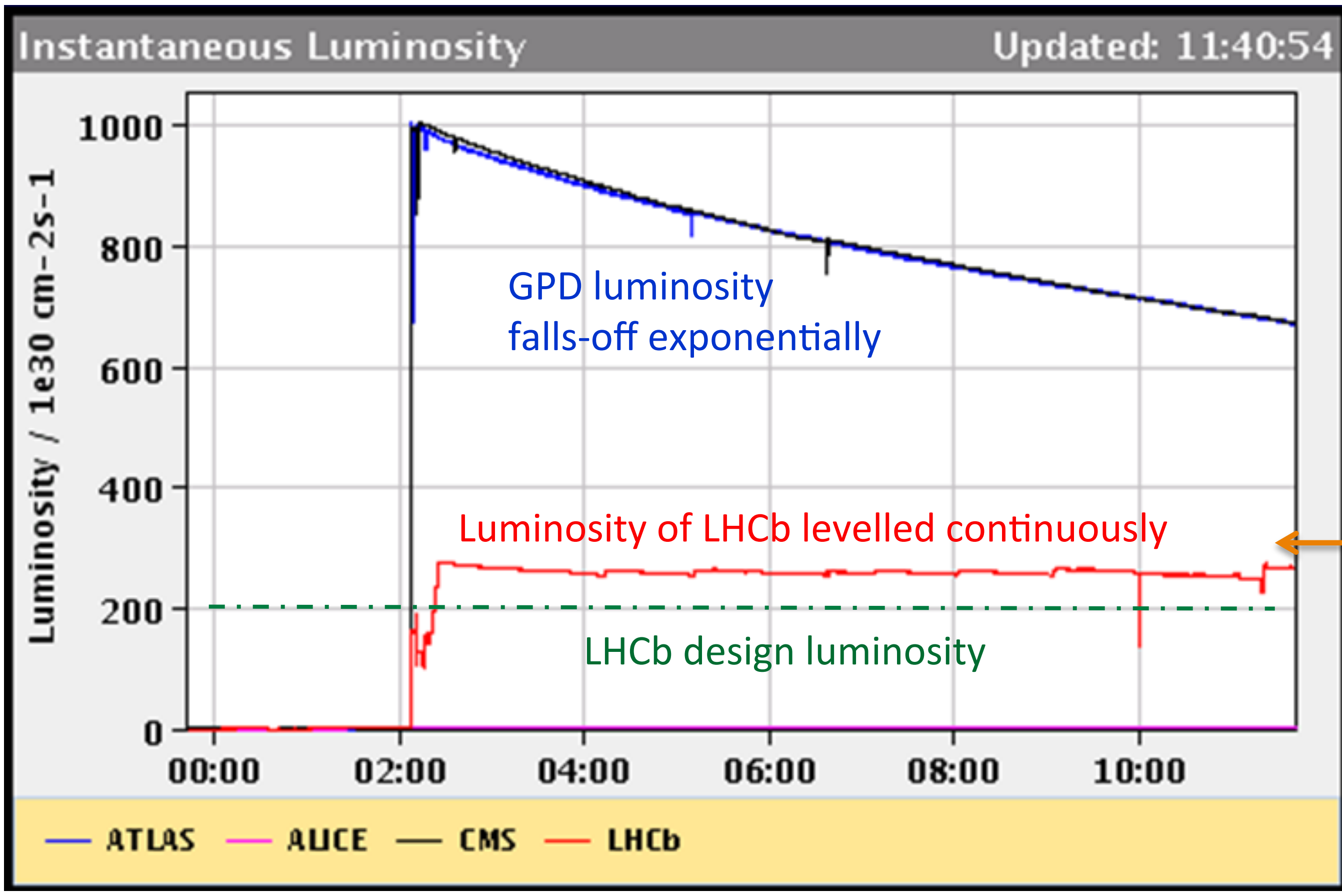
LHCb Status Report

106th LHCC Meeting

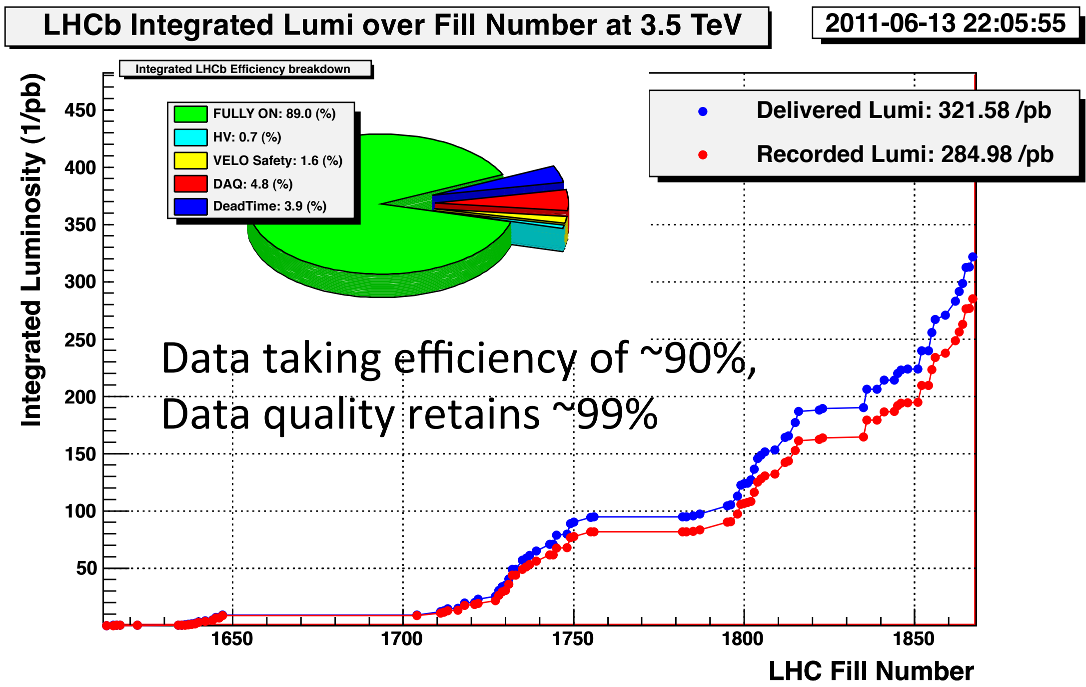
For the LHCb Collaboration, Patrick Robbe, LAL Orsay, 15 June 2011

Introduction



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

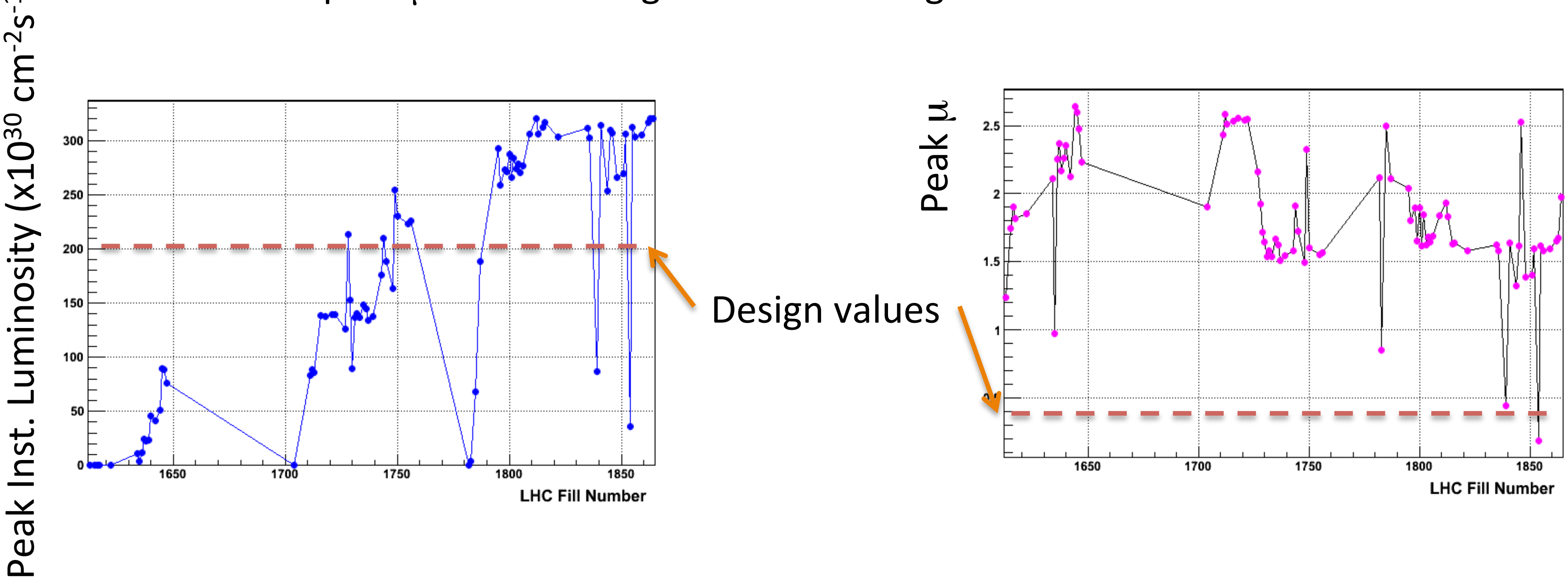
Outline



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

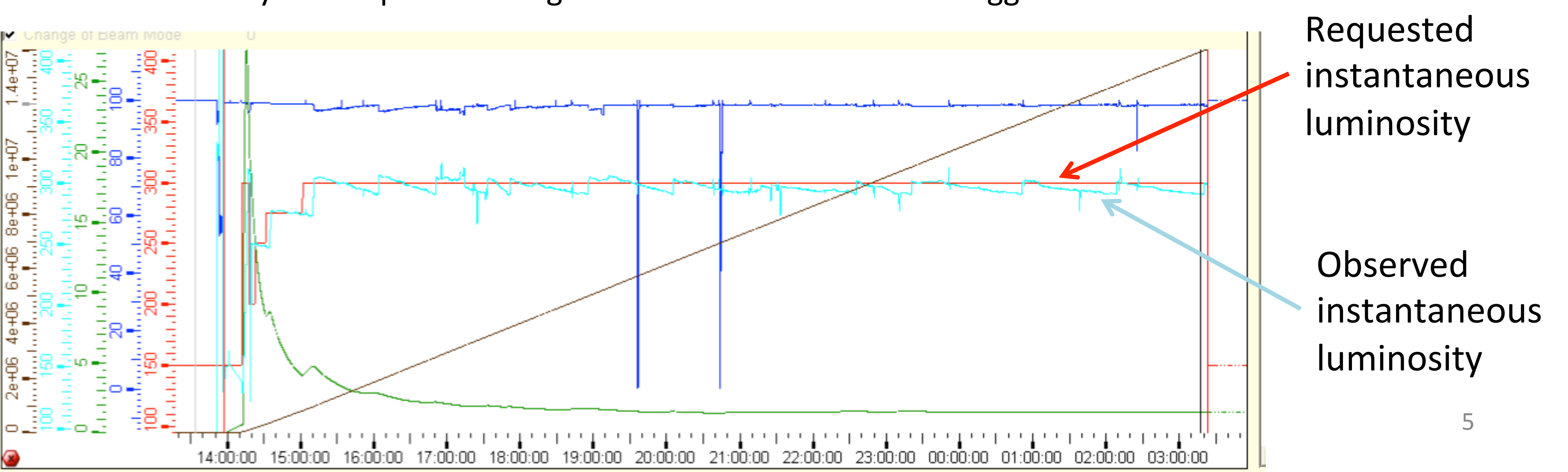
Operation Strategy

- Luminosity and trigger strategy:
  - Maintain μ (number of visible interactions per crossing) < 2.5
  - Maintain the instantaneous luminosity ~3×10^{32} $cm^{-2}s^{-1}$, reached on 27 May 2011:
    - Implies μ is decreasing when increasing the number of bunches.



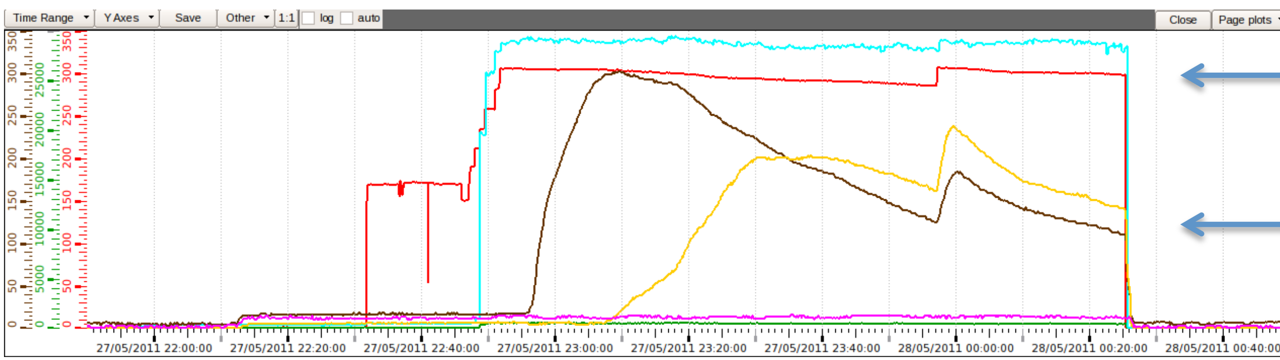
Luminosity Leveling

- 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
  - μ<2.5 for detector hardware and physics analyses
  - Physics dead-time <5%
  - Physics output to storage 3 kHz + 1 kHz of technical triggers



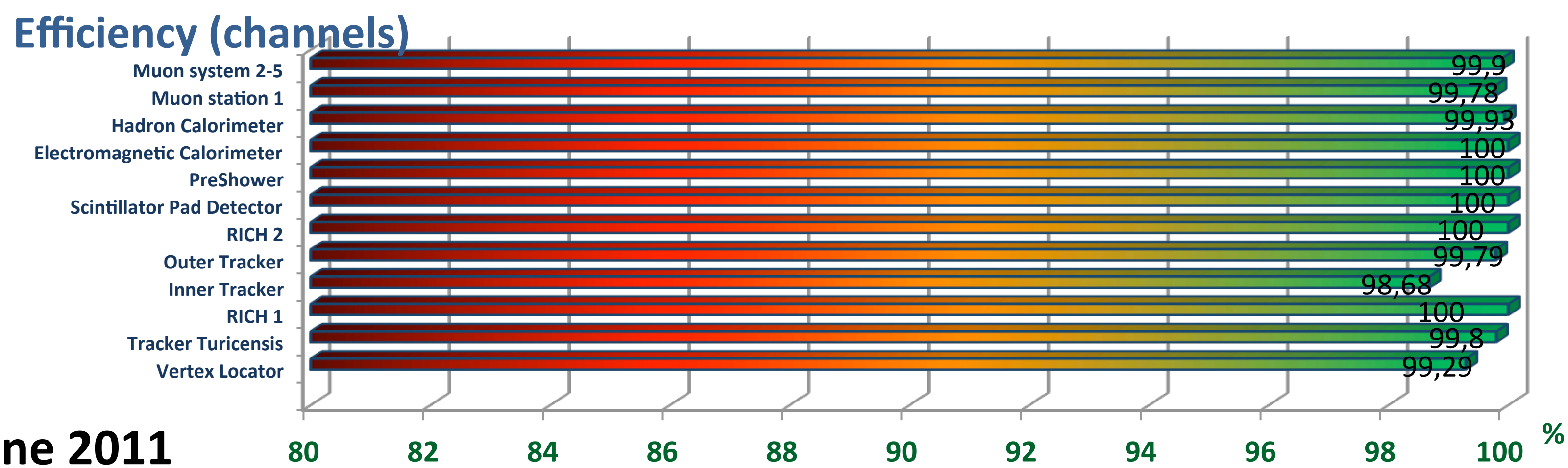
Detector Status

- 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

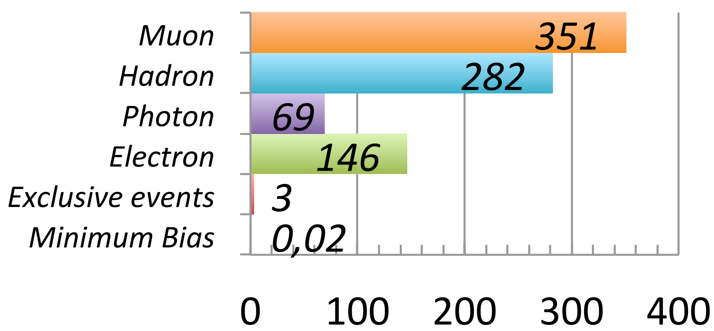


June 2011

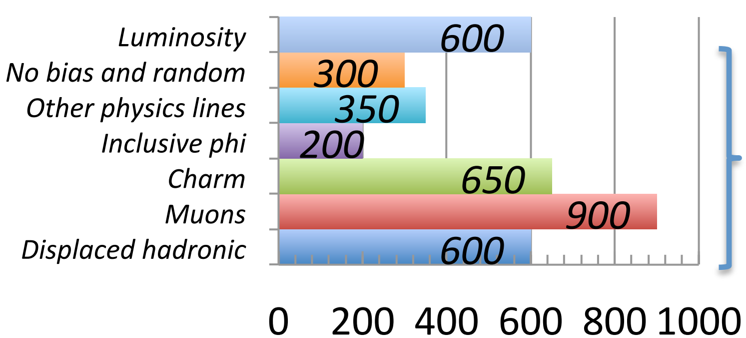
Trigger

- With 1092 bunches, 3×10^{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)

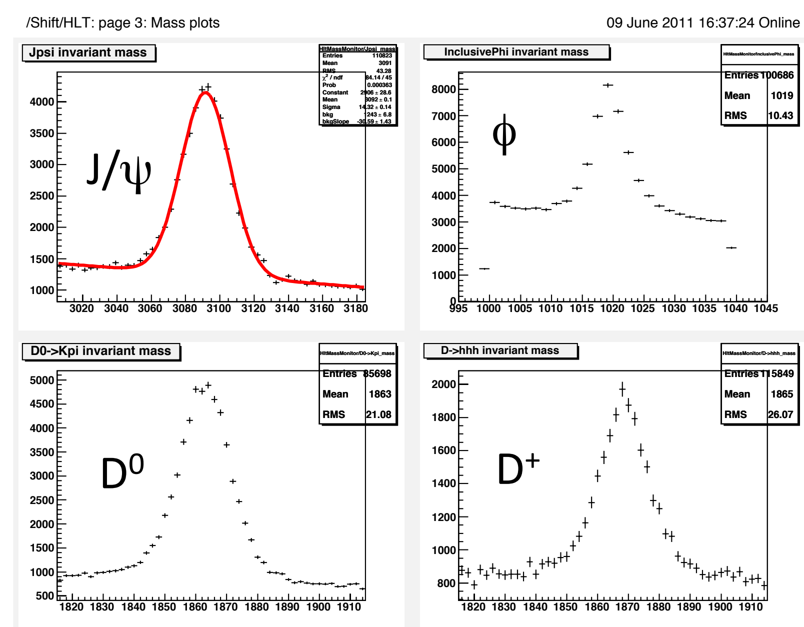


HLT Output Rate (Hz)



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)

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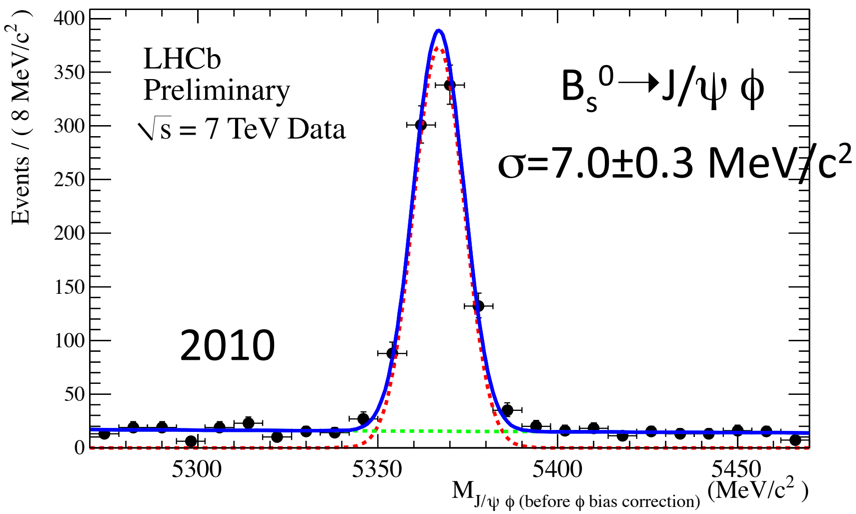
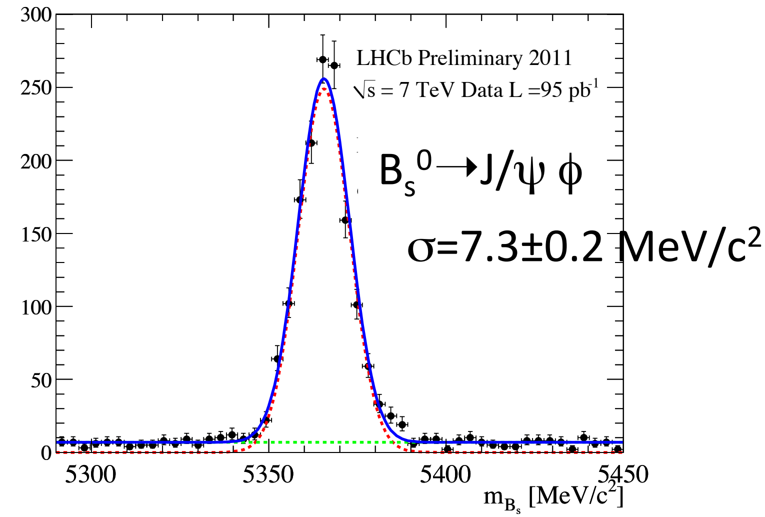
Similar performances with 2011 data





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 ± 0.29
$M(B^0 \to J/\psi K^{*0})$	=	$5279.54 \pm 0.15\,(\text{stat}) \pm 0.16\,(\text{syst})$	5279.50 ± 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 ± 0.30
$M(B^0_s \to J/\psi\phi)$	=	$5366.60 \pm 0.28\,(\text{stat}) \pm 0.21\,(\text{syst})$	5366.30 ± 0.60
$M(\Lambda_b \to J/\psi\Lambda)$	=	$5619.49 \pm 0.70\,(\text{stat}) \pm 0.19\,(\text{syst})$	5620.2 ± 1.6
$M(B^+_c \to J/\psi\pi^+)$	=	$6268.0 \pm 4.0\,(\text{stat}) \pm 0.6\,(\text{syst})$	6277 ± 6

Production: quarkonium

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

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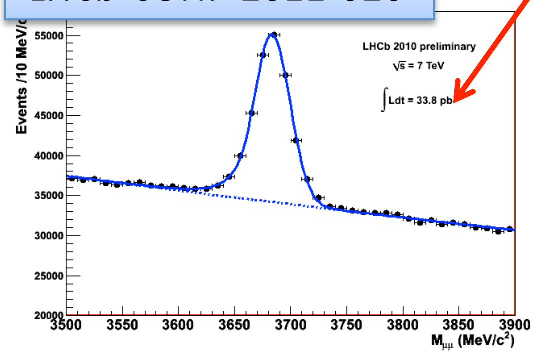
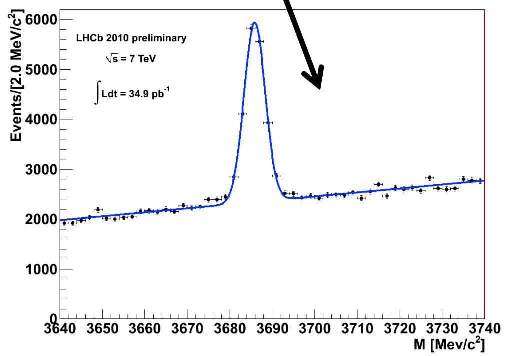
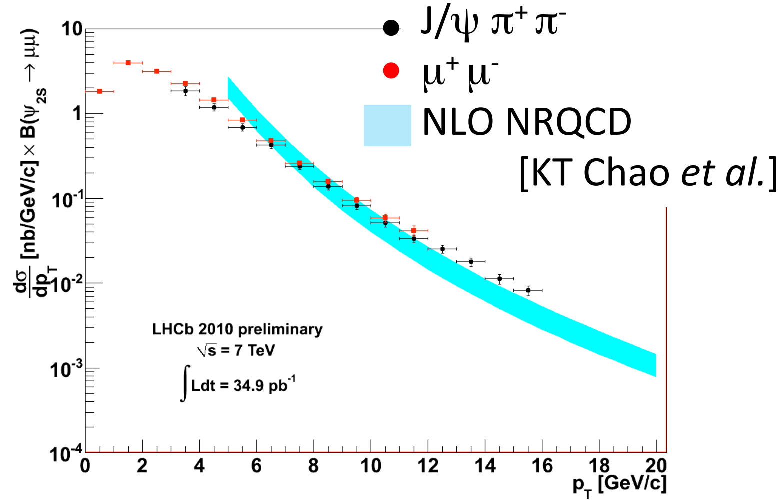
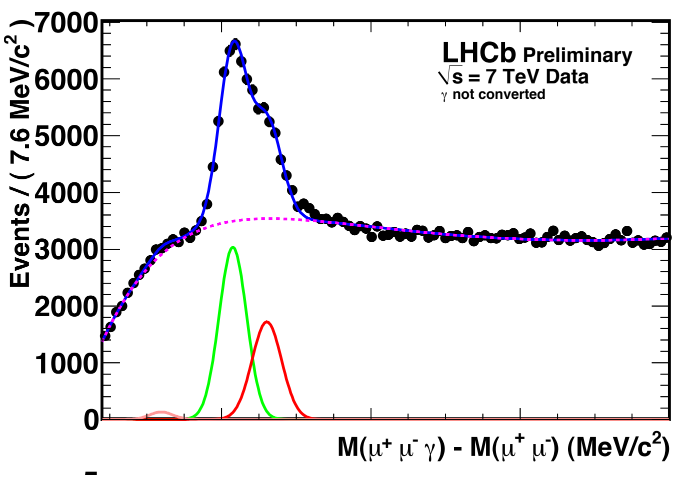
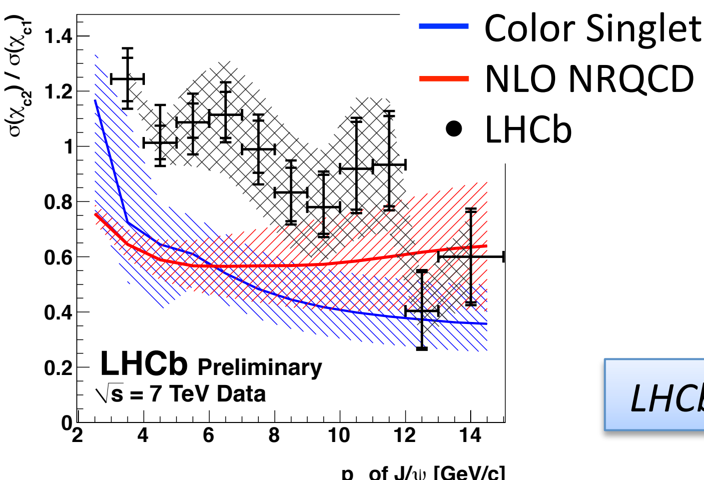






- Prompt $\chi_{c(1,2)} \rightarrow J/\psi\ \gamma$, with photon reconstructed in ECAL





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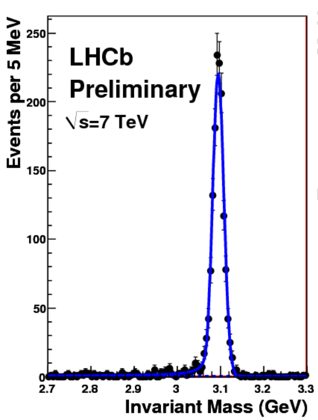
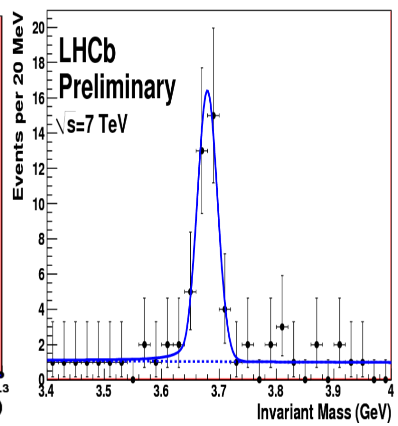
Production: exclusive charmonium

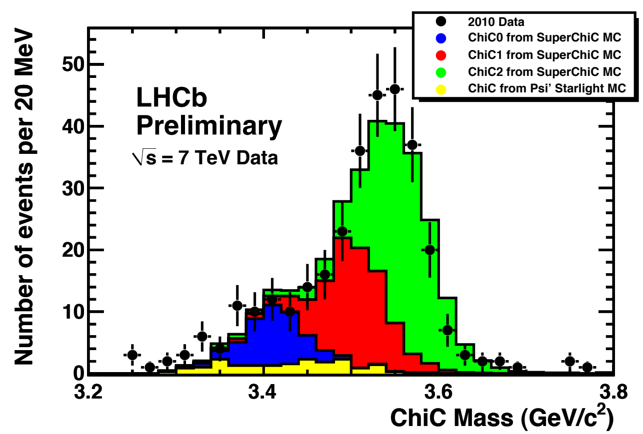
- Production of 1 charmonium state and nothing else: possible if one colour-less object is exchanged.
- Thanks to VELO, capability also to detect backward charged tracks.
- Study of pomeron and odderon in a clean environment.



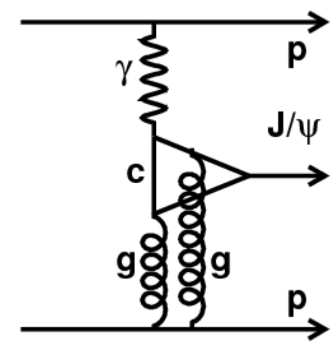
J/ψ



ψ (2S)



$\chi_{c0,1,2}$



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

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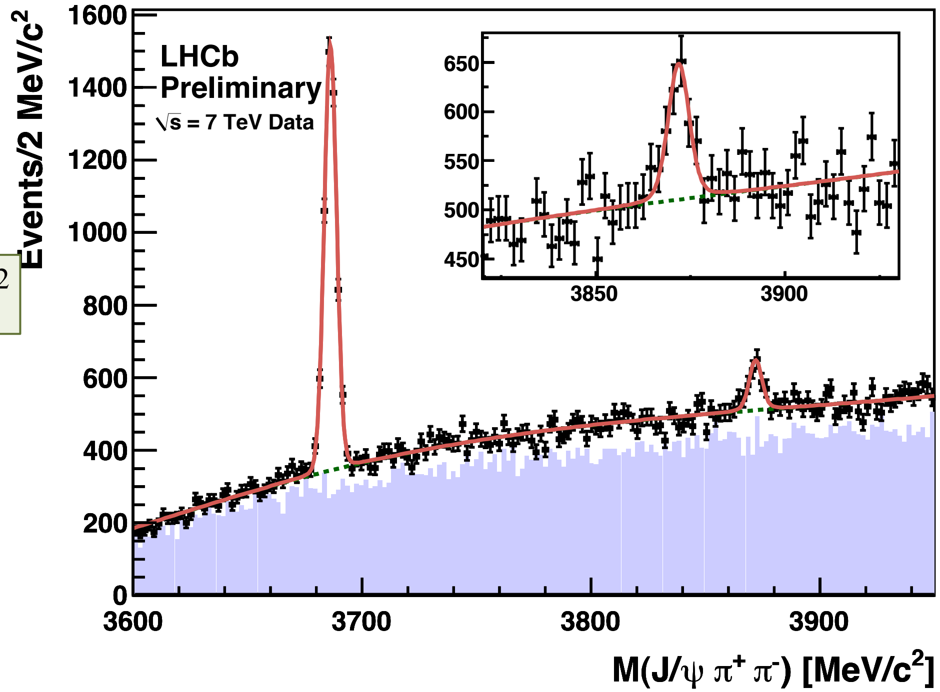
Production: exotic states

- 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.

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



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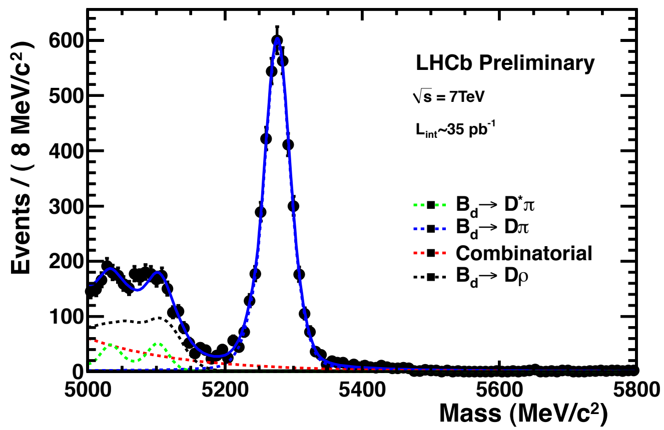
$\psi(2S)\to J/\psi\,\pi^+\pi^-$ and $X(3872)\to J/\psi\,\pi^+\pi^-$, with $J/\psi\to\mu^+\mu^-$

Production: *B* fragmentation, f_s/f_d

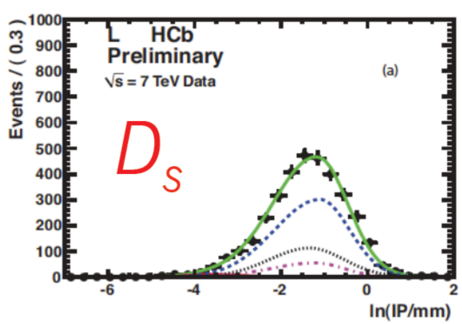
- $f_{u,d,s,baryon}$=probability for a b quark to hadronize in a B^+, B^0, B_s or b-baryon.
- f_d/f_s measured from ratios of B^0 and B_s reconstructed in:
  - Hadronic decay modes: $B_s^0 \to D_s^- \pi^+$ compared to $B^0 \to D^- \pi^+$ or $B^0 \to D^- K^+$

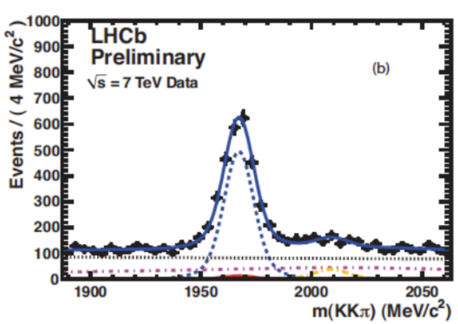
LHCb-CONF-2011-013



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

  - Semi-leptonic decay modes: $B \to (D^+, D_s^+)\mu\nu X$

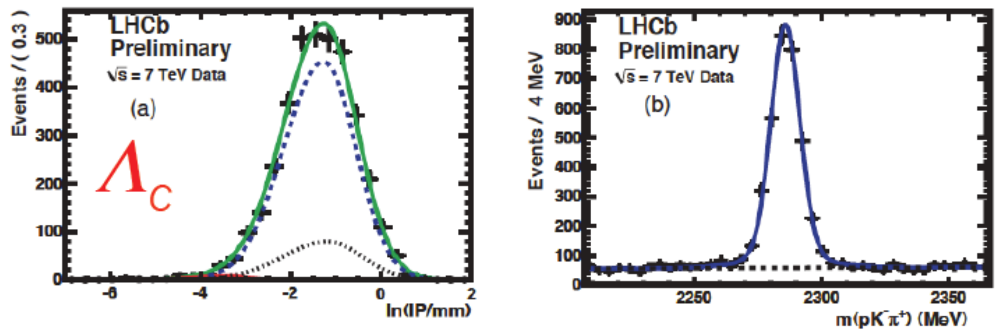




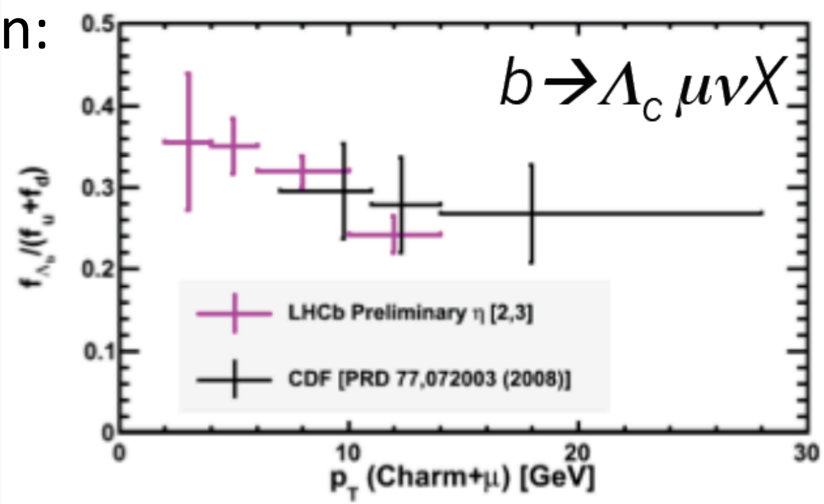
$$\frac{f_s}{f_d} = 0.272 \pm 0.008^{+0.024}_{-0.022}$$

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:

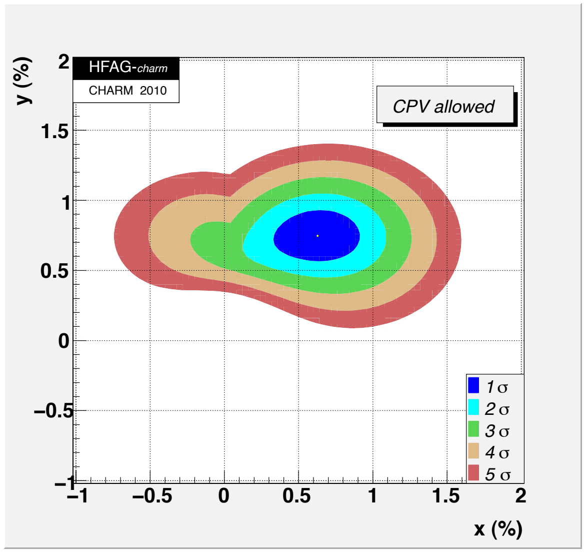


$$\frac{f_{\Lambda_b}}{f_u+f_d} = (0.401 \pm 0.019 \pm 0.106) - (0.0120 \pm 0.0025 \pm 0.0012) \times p_{\mathrm{T}}\,/\,\mathrm{GeV}$$

Charm

LHCb-CONF-2010-013

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



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

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

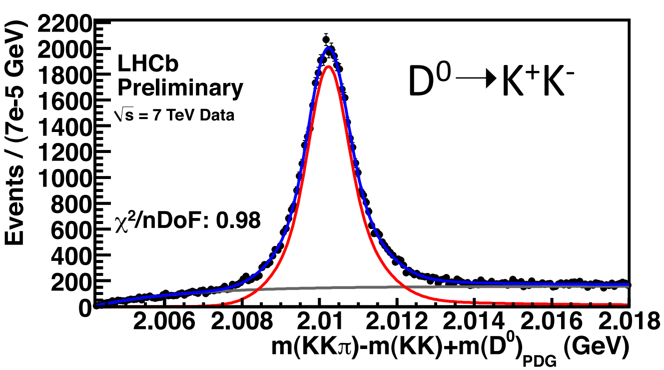
- At the output of the L0 trigger, half of the events contain a charm: need to have in HLT exclusive selections of the interesting decay modes: ~1 kHz output rate of pure charm events.

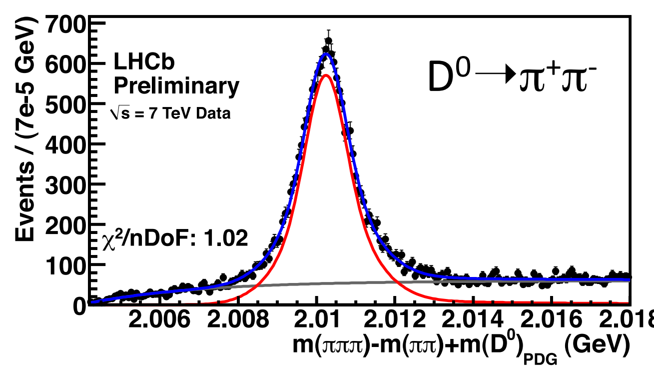
Charm: time integrated CP asymmetry

- 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 $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$, from a D^{*+} decay (tagged).

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

- 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 $1fb^{-1}$

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

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

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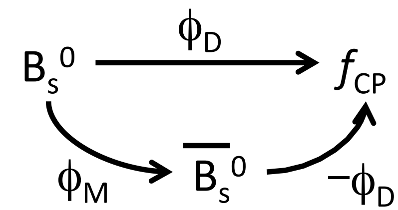
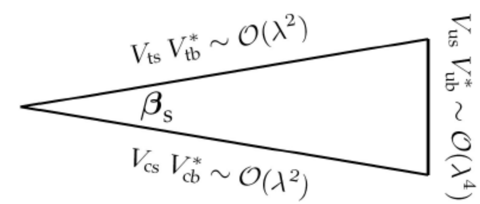
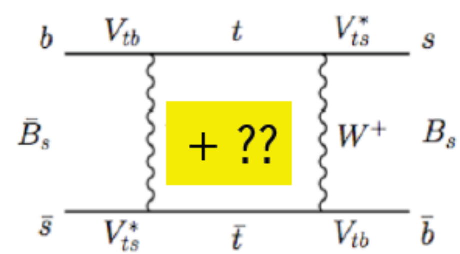
CP Violation in B_s decays : ϕ_S



- 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, ϕ_S is well determined: $\phi_S = -2\beta_S = -0.0363 \pm 0.0017$ rad, up to penguin diagram phase contributions ($10^{-4} - 10^{-3}$).



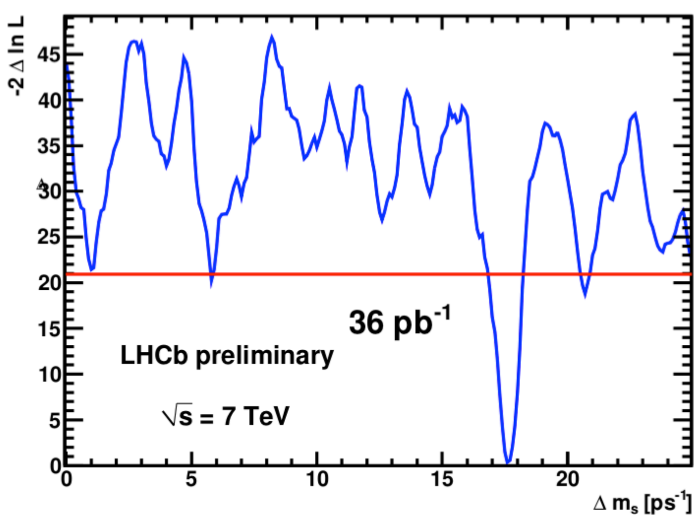
- The mixing phase, $\phi_M \approx 0$ in Standard Model can be modified by New Physics and enhance the measured ϕ_S.

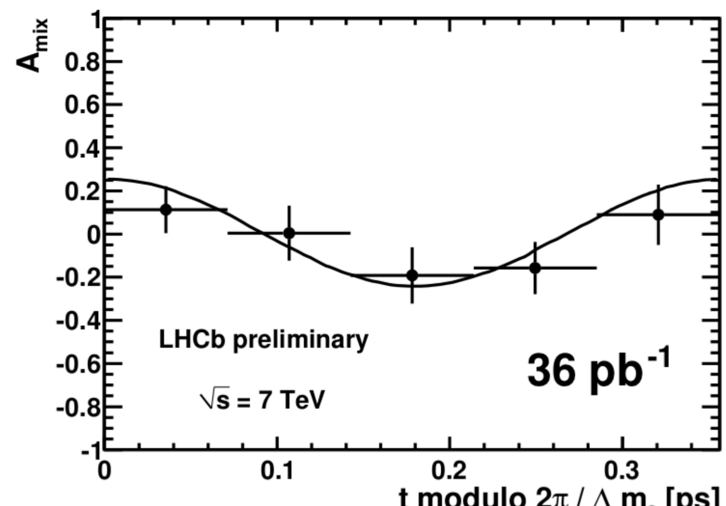


- Since the decay is $P \to VV$, the final state is superposition of states with different CP value: the measurement requires a complex ***tagged***, ***time-dependent***, ***angular analysis***.

Tagged: measurement of B mixing

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





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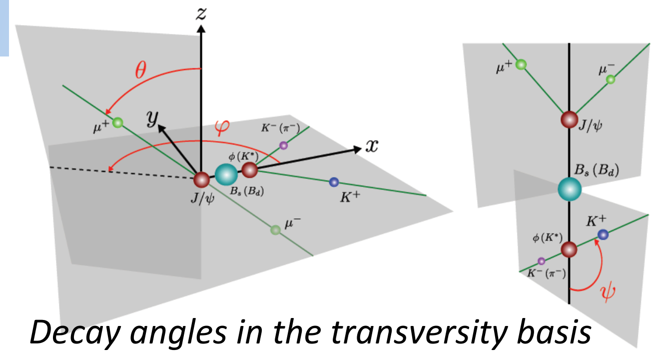
$$\Delta m_s = 17.63 \pm 0.11 \pm 0.04\,\mathrm{ps}^{-1}$$

Single world's best measurement

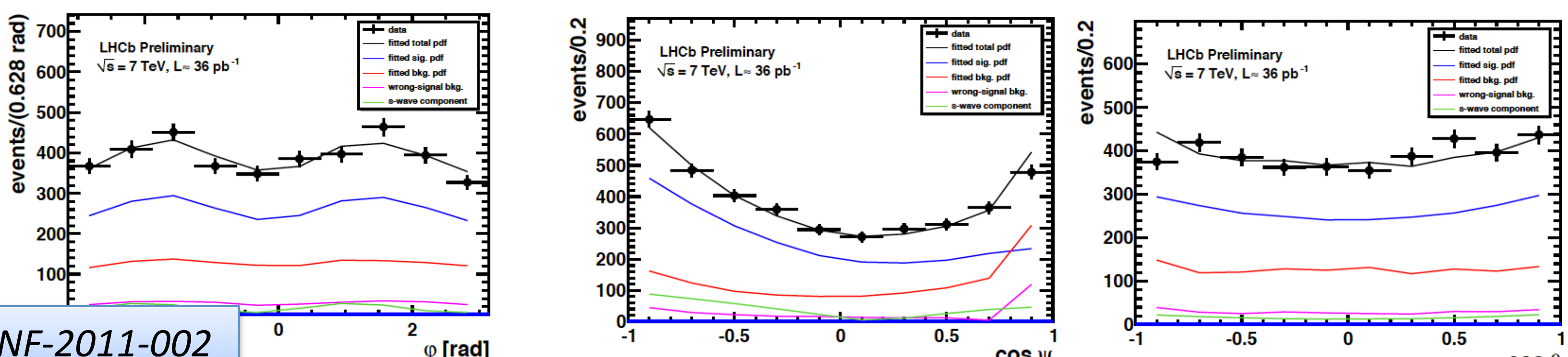
Angular analysis: $B^0 \to J/\psi\ K^{*0}$ polarization amplitudes



Decay angles in the transversity basis

- Similar angular analysis required: simultaneous fit to m, t, ϕ, ψ, θ.
- 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
$\|A_{\|\|}(0)\|^2$	$0.252 \pm 0.020_{stat.} \pm 0.016_{syst.}$	$0.211 \pm 0.010_{stat.} \pm 0.006_{syst.}$
$\|A_{\perp}(0)\|^2$	$0.178 \pm 0.022_{stat.} \pm 0.017_{syst.}$	$0.233 \pm 0.010_{stat.} \pm 0.005_{syst.}$
$\delta_{\|\|}$	$-2.87 \pm 0.11_{stat.} \pm 0.10_{syst.}$	$-2.93 \pm 0.08_{stat.} \pm 0.04_{syst.}$
$\delta_{\perp}$	$3.02 \pm 0.10_{stat.} \pm 0.07_{syst.}$	$2.91 \pm 0.05_{stat.} \pm 0.03_{syst.}$



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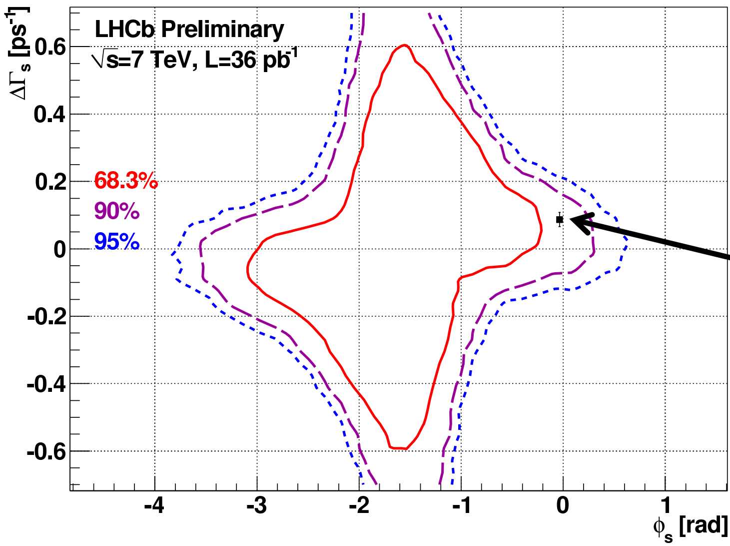
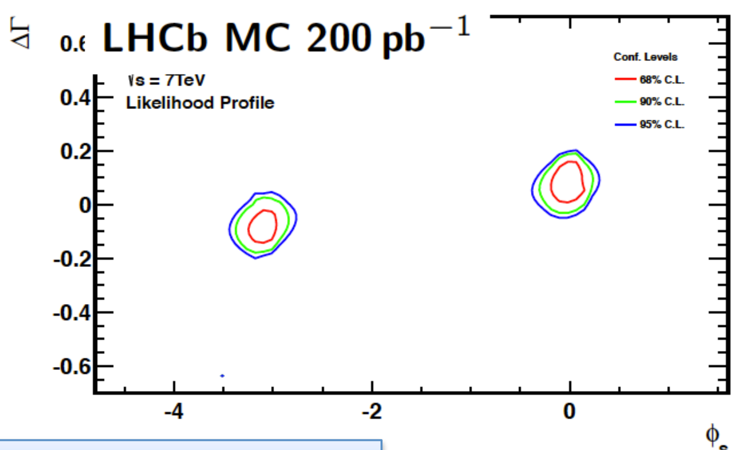
$B_s^0 \to J/\psi\ \phi$: measurement of ϕ_s



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



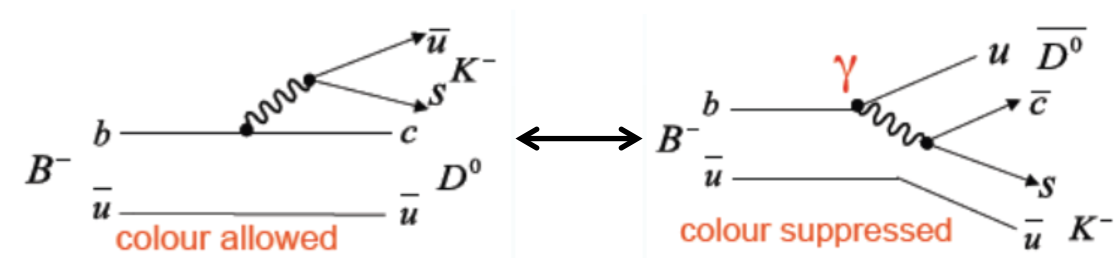
- With the same analysis performances, expect sensitivity of 0.13 rad on ϕ_s with 1 fb^{-1}.
- Improvements to the analysis expected in 2011 (use of same side tagging, use $B_s^0 \to J/\psi\ f_0$, …) will increase this sensitivity.
- World's best measurement in 2011.

	LHCb 36 pb^{-1}	CDF 5.2 fb^{-1}
$B_s \to J/\psi\,\phi$	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	$3.5 \pm 1.4\%$

LHCb-CONF-2011-006

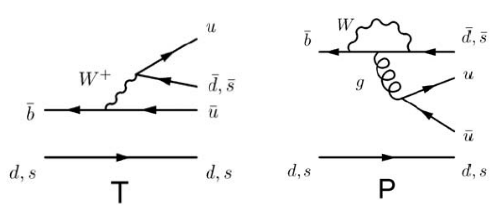
CP Violation in B decays : γ angle

- γ 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]

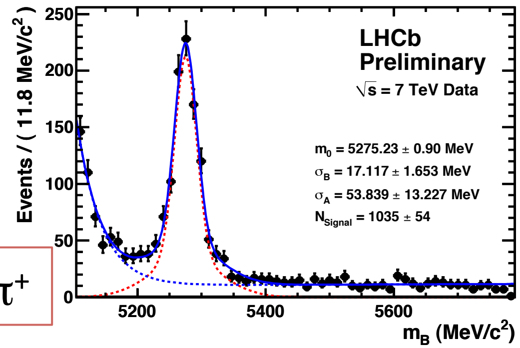
  - Interferences between tree diagrams and penguin diagrams of charmless B decays: very sensitive to New Physics in loops



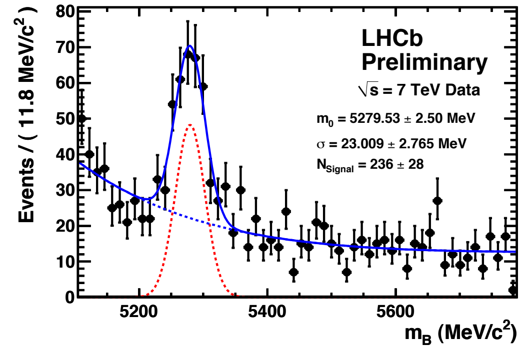
- Full time dependent analysis will take time, but interesting results already from time-integrated rates and lifetimes.

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

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

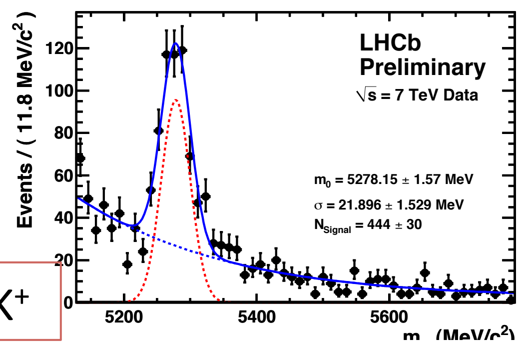


$B^+ \rightarrow D^0(K^+K^-)\pi^+$



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

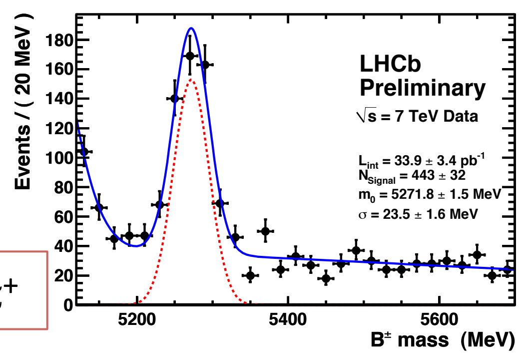
- ADS



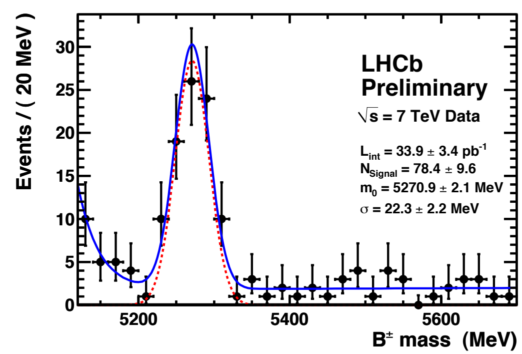
$B^+ \rightarrow D^0(K^-\pi^+)K^+$

Expect sensitivity of 5° on γ 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

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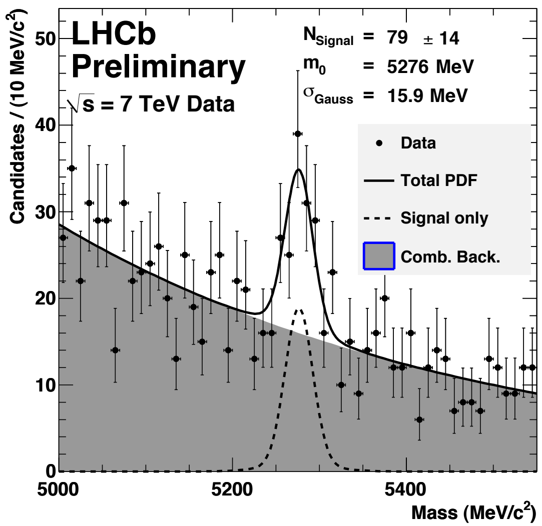
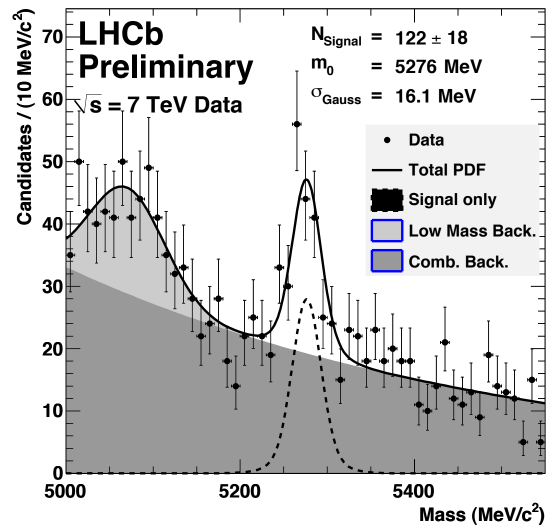
- Can also use higher multiplicity decays.
- First observation of the Cabibbo-suppressed decays:



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



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

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

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

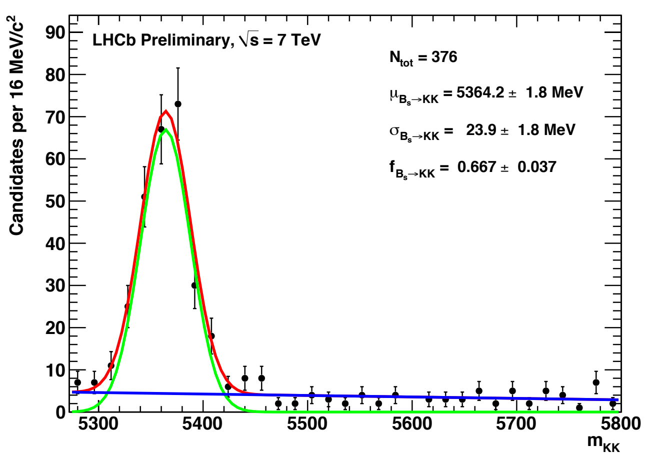
- Up to 6 tracks in the final state: good tracking and trigger performances.

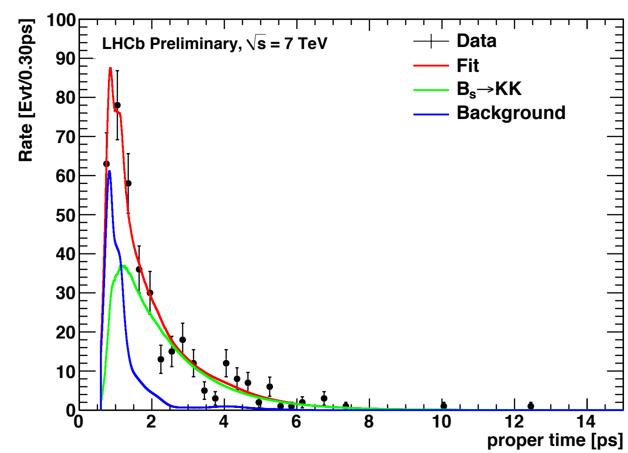
$B_s^0 \to K^+ K^-$ Lifetime

- 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.

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

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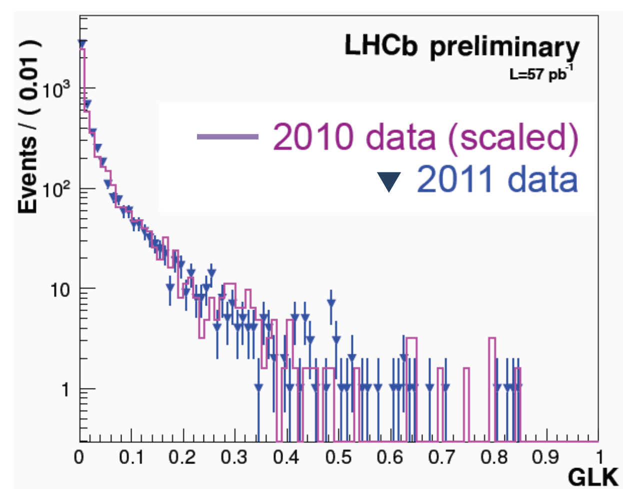
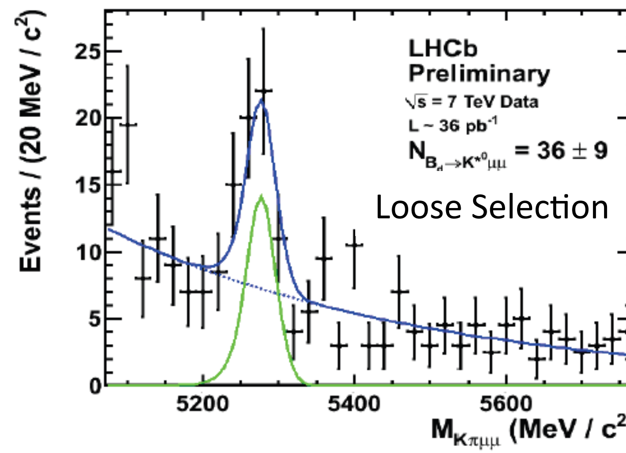
B rare decays

- 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 $B(B_s^0 \rightarrow \mu^+\mu^-) \sim 5\text{-}10 \times 10^{-9}$ (SM: $\sim 3 \times 10^{-9}$)
- 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.

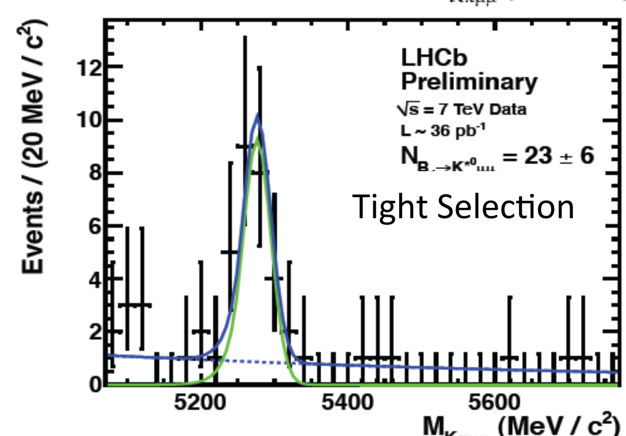


$B^0 \rightarrow K^{*0}\mu^+\mu^-$

- Promising reconstructed $B^0 \rightarrow K^{*0}\mu^+\mu^-$ 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)



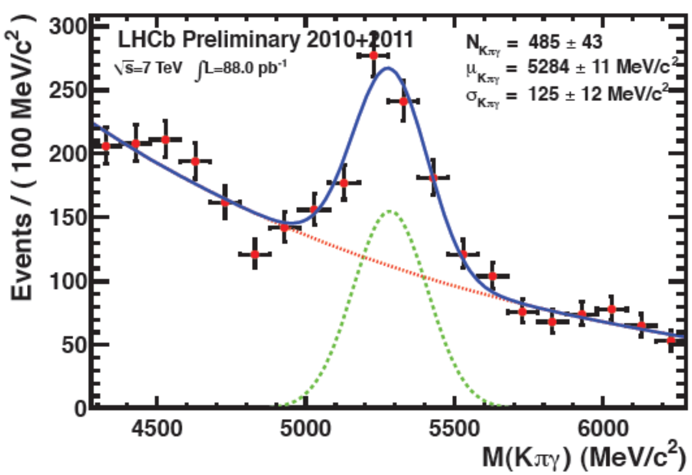
- or 600 events with purer selection (B/S=0.2)



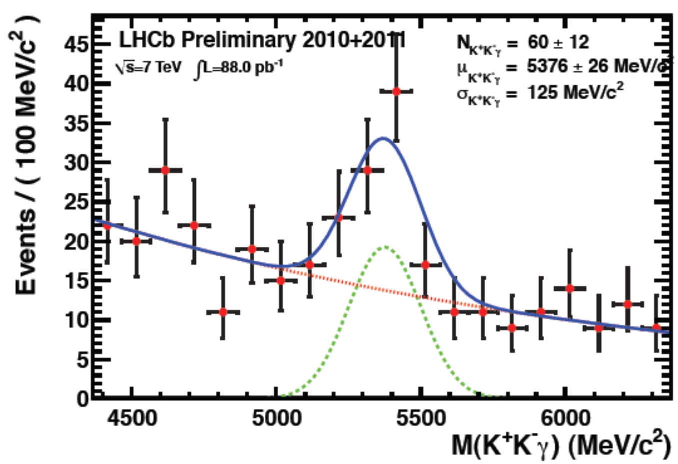
- Preliminary results on A_{FB} expected during the summer.

Radiative Decays

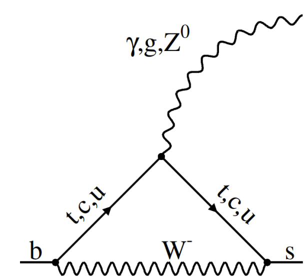
- Measure photon polarization (through angular analysis) and extract: $\left|\frac{A(B\to\Phi\lambda_R)}{A(B\to\Phi\lambda_L)}\right|$
- Rely on photon trigger and photon reconstruction in the Electromagnetic Calorimeter.
- Improve existing measurement of $B(B_s^0\to\phi\gamma)/B(B^0\to K^{*0}\gamma)$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



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

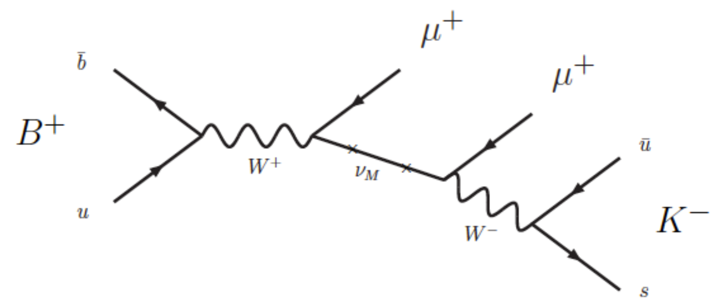


$B_s^0\to\phi\gamma$, expect 600 events in 1 fb^{-1}



Search for $B^+ \to h^- \mu^+ \mu^+$

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



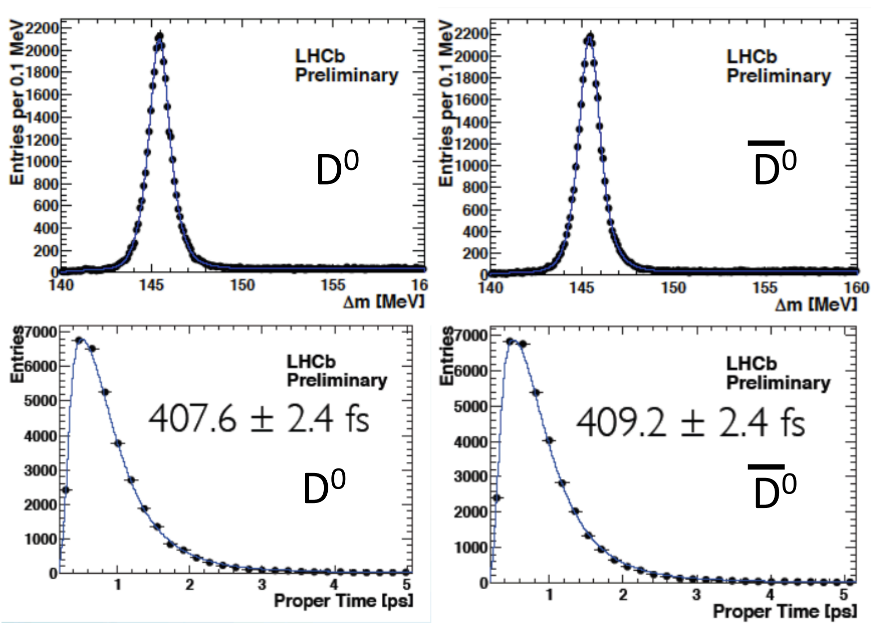
- < 0.3 (0.1) background events expected in $\pi\mu\mu$ ($K\mu\mu$) mode
- Zero events observed in both signal regions and sidebands
- Limits:
  - $B(B^+ \to K^- \mu^+ \mu^+) < 4.3 \times 10^{-8}$ @ 90% C.L.
  - $B(B^+ \to \pi^- \mu^+ \mu^+) < 4.5 \times 10^{-8}$ @ 90% C.L.
  - Factor 40 (30) improvement 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:
  - ϕ_s with $B_s^0 \to J/\psi\ \phi$
  - $B_s^0 \to \mu^+ \mu^-$
  - $B^0 \to K^{*0} \mu^+ \mu^-$
  - Competitive γ 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 5σ)
  - 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_Γ" 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

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

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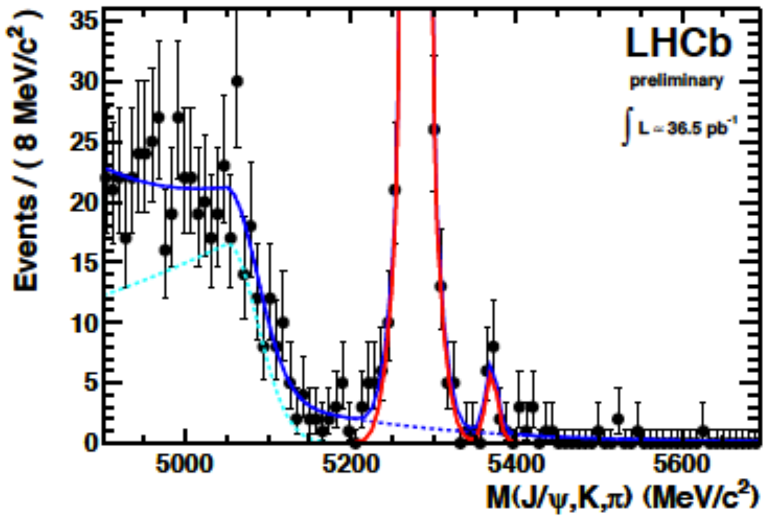

- Will allow to control penguin contamination in ϕ_s measurement with $B_s^0 \to J/\psi\ \phi$.

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

Time dependent CPV: measurement of sin2β

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

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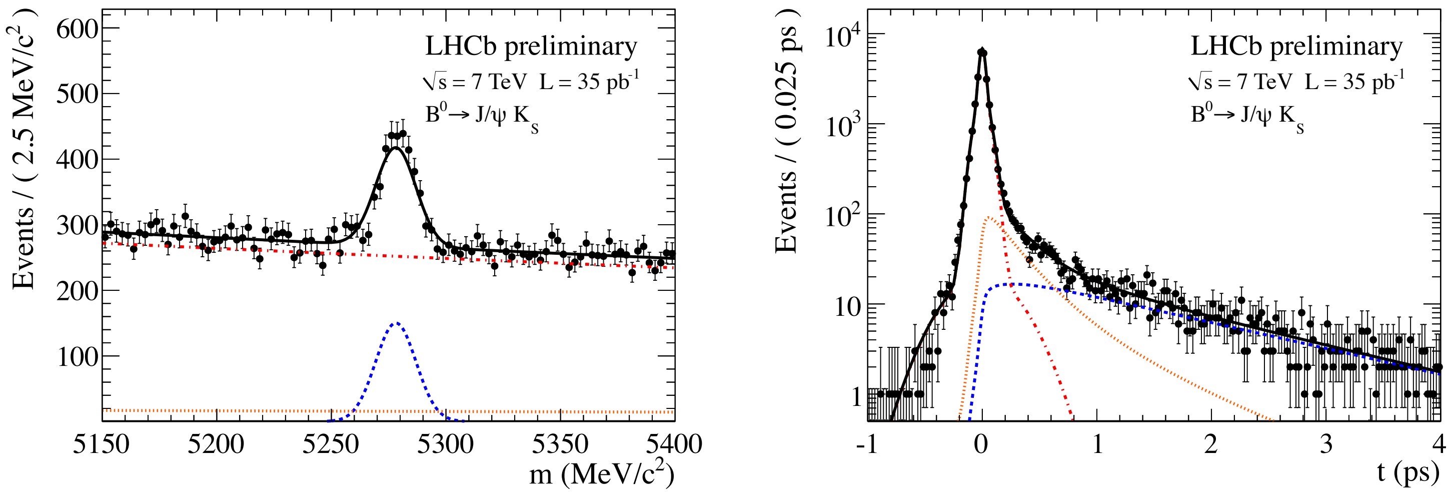

- Tagging with opposite and same sign: $\varepsilon(1-2\omega)^2 \approx 2.8\%$
- Proper time resolution: ≈50 fs
- Sine term of asymmetry (sin2β if no direct CP violation nor CP violation in B^0 mixing):

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

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