

LHCC Open Session – Status LHCb

Niels Tuning

On behalf of the LHCb collaboration

Outline

1) LHCb detector in LS1

2) Selection of recent physics results

- Unitarity angle γ
- Electroweak penguin decays
- CP violation in B_s^0 system
- Nuclear attenuation with ions

$$B^\pm \rightarrow DK^\pm$$

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

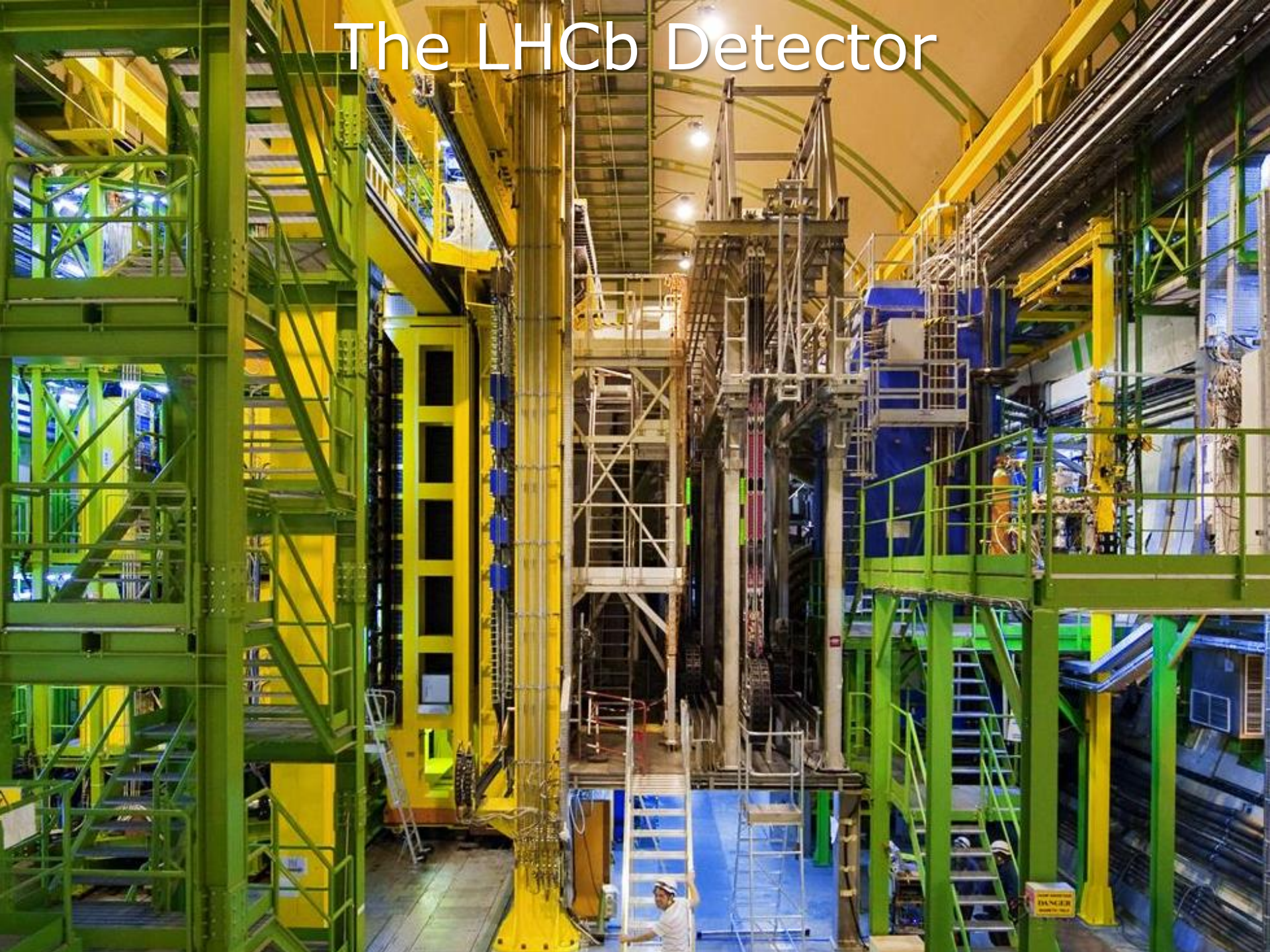
$$B_s^0 \rightarrow K^+ \pi^-$$

$$pPb \rightarrow X + J/\psi(\mu^+ \mu^-)$$

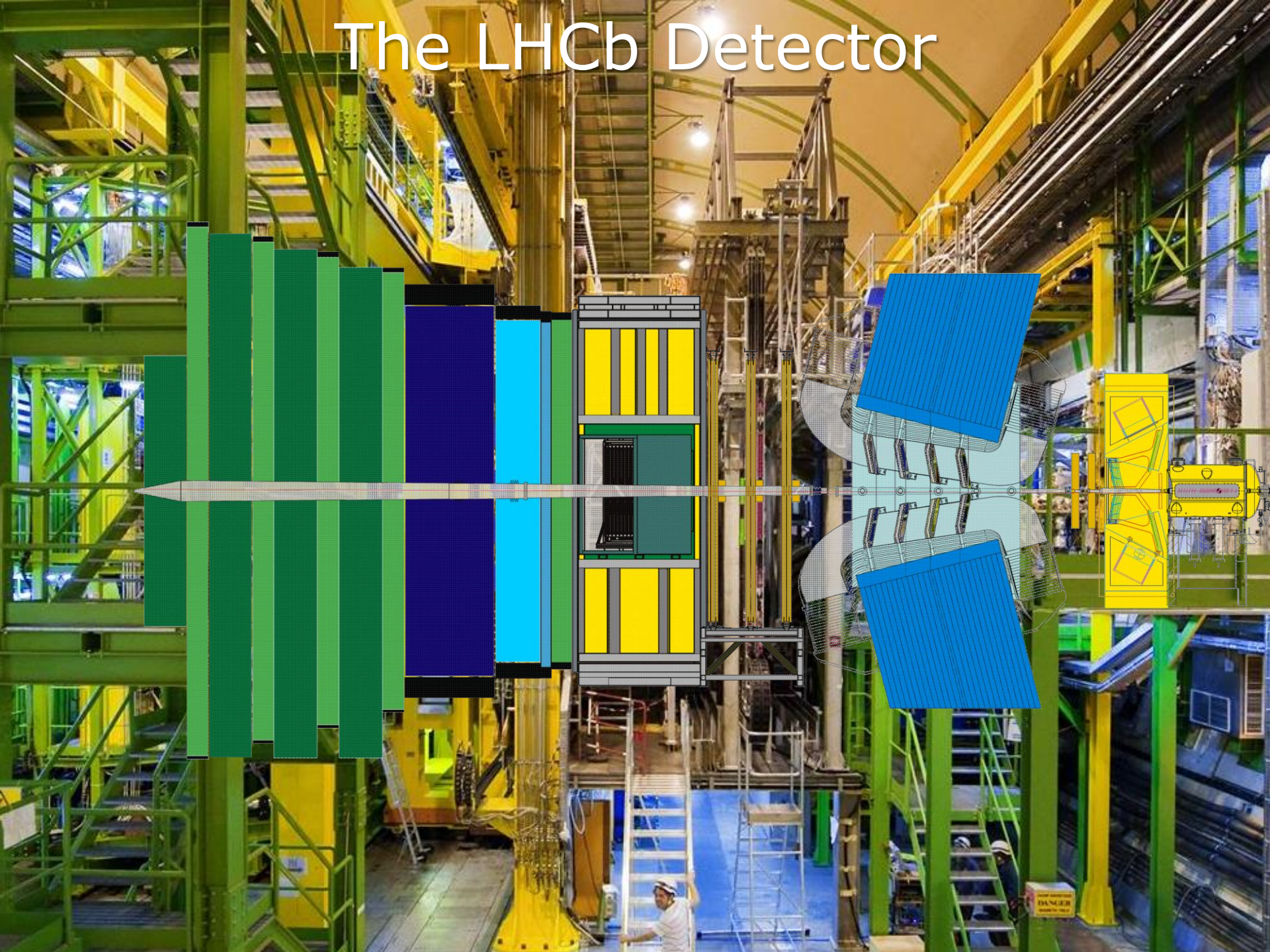
3) LHCb upgrade

Previous LHCC [13/14 Mar 2013](#)

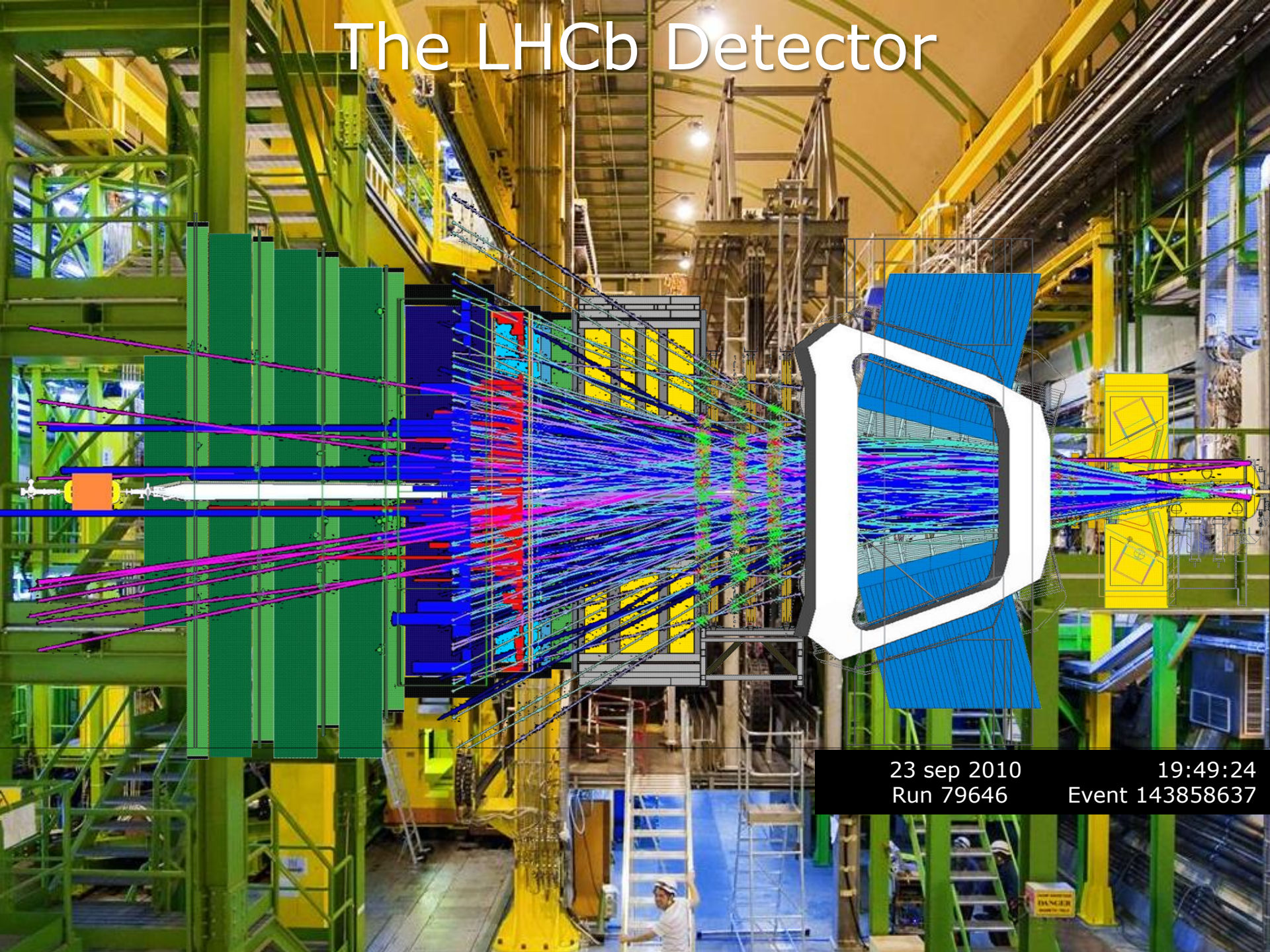
The LHCb Detector



The LHCb Detector



The LHCb Detector



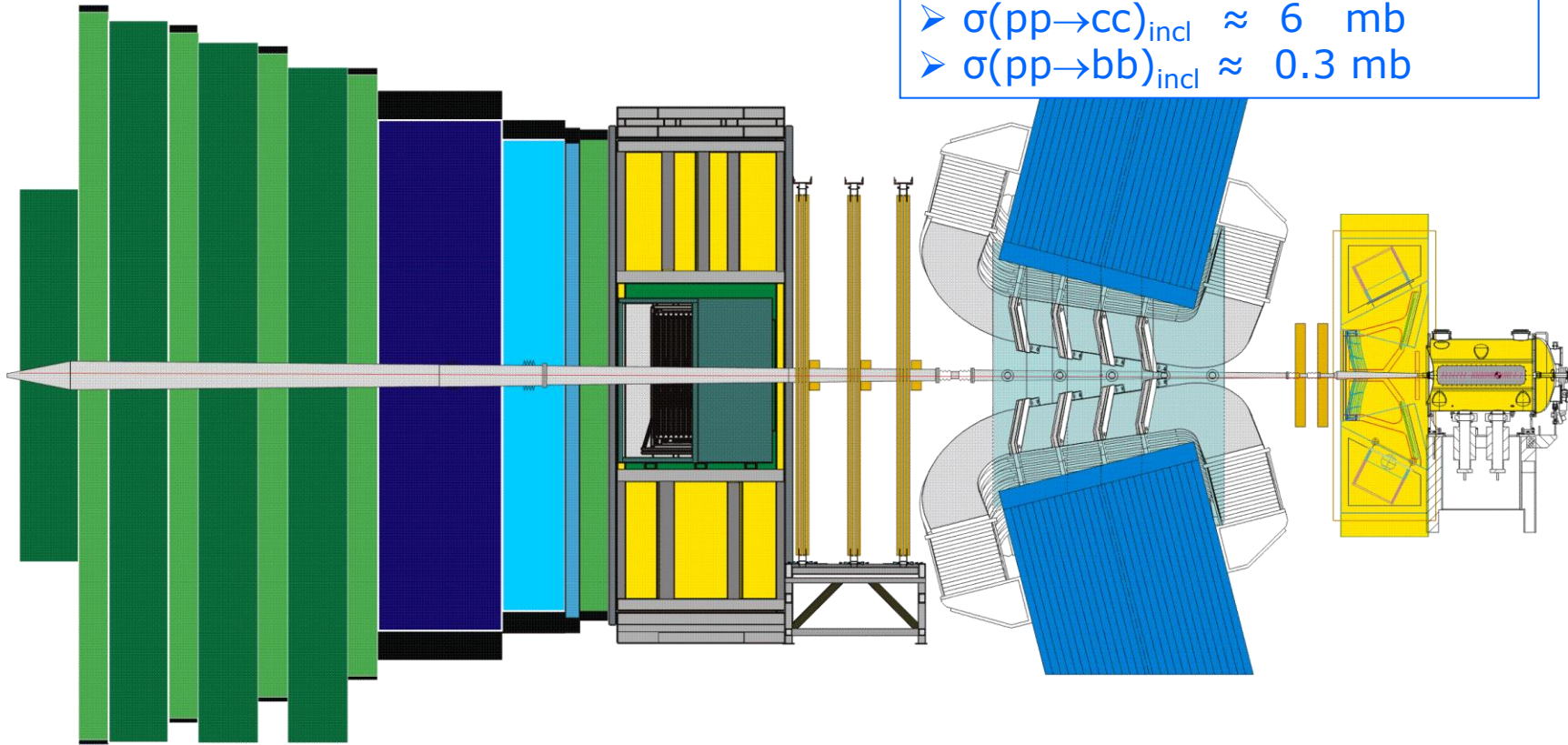
23 sep 2010
Run 79646

19:49:24
Event 143858637

The LHCb Detector

Forward arm spectrometer

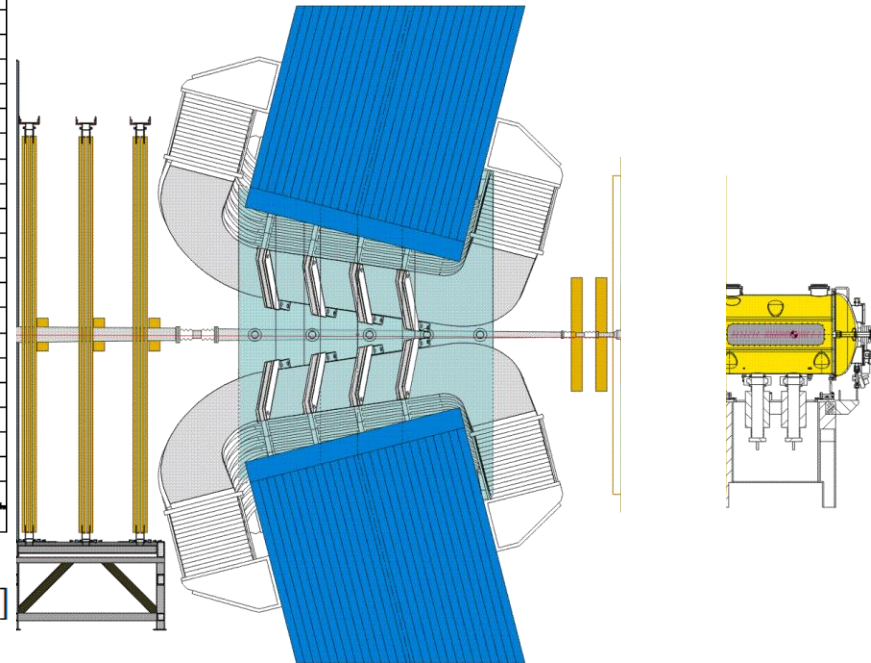
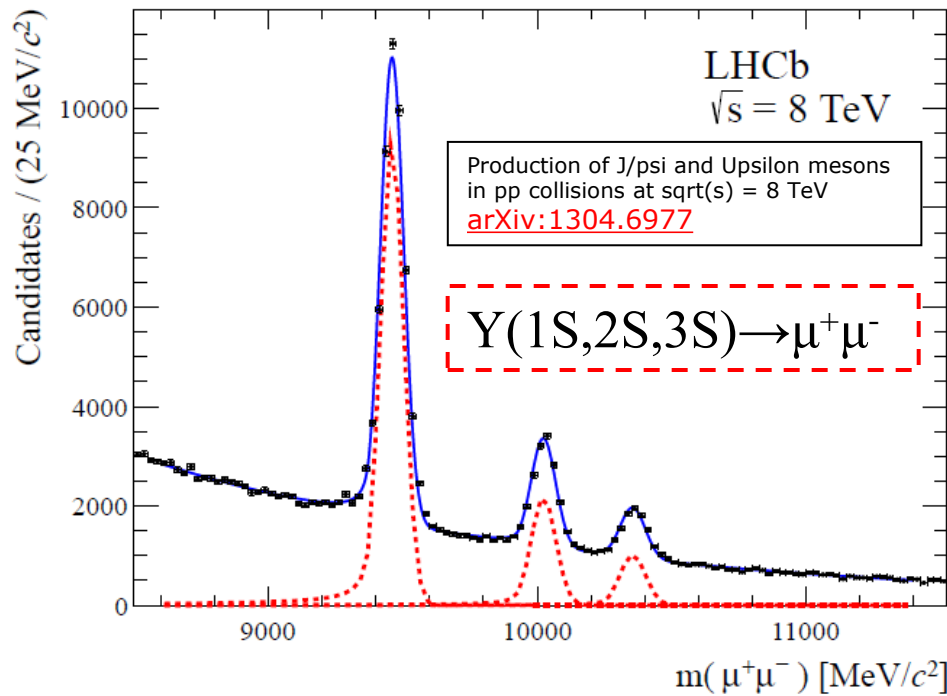
- $2 < \eta < 5$
- $\sigma(pp \rightarrow X)_{\text{inel}} \approx 60 \text{ mb}$
- $\sigma(pp \rightarrow cc)_{\text{incl}} \approx 6 \text{ mb}$
- $\sigma(pp \rightarrow bb)_{\text{incl}} \approx 0.3 \text{ mb}$



The LHCb Detector

Tracking: $dp/p \sim 0.4\text{-}0.6\%$

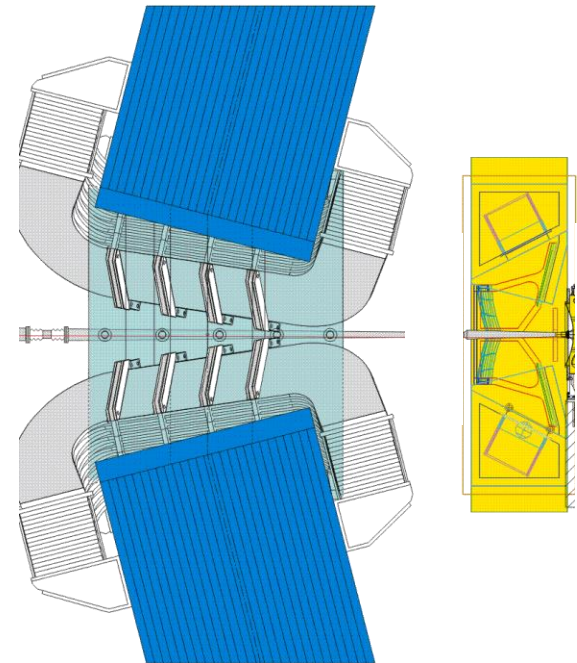
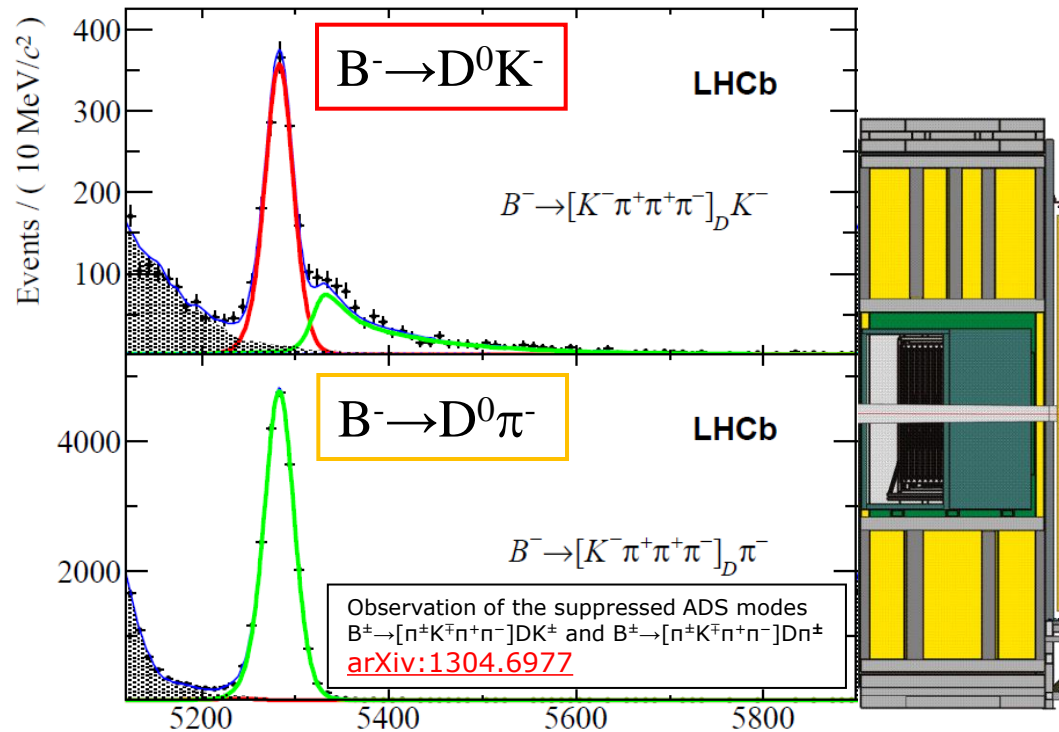
Excellent mass resolution



The LHCb Detector

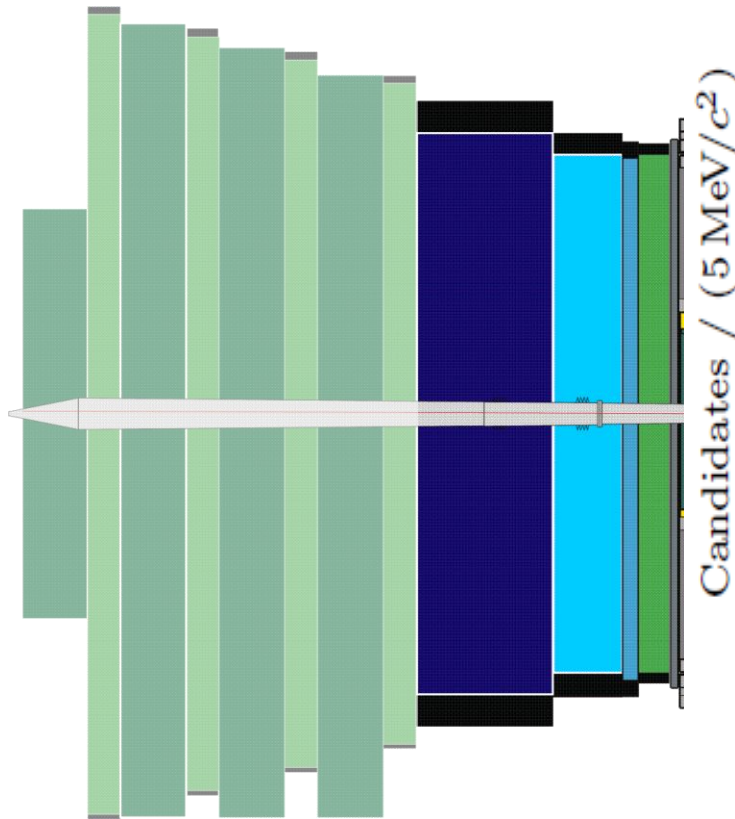
PID: $\varepsilon(K \rightarrow K) \sim 95\%$, $\varepsilon(\pi \rightarrow K) \sim 5\%$,

Excellent PID performance

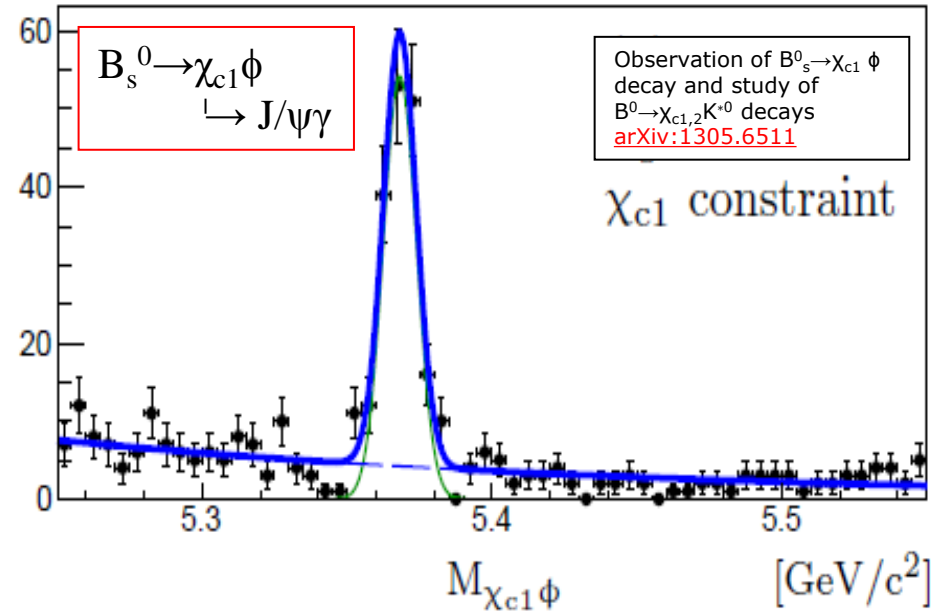


The LHCb Detector

CALO: $\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$ (ECAL)
 $\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$ (HCAL)

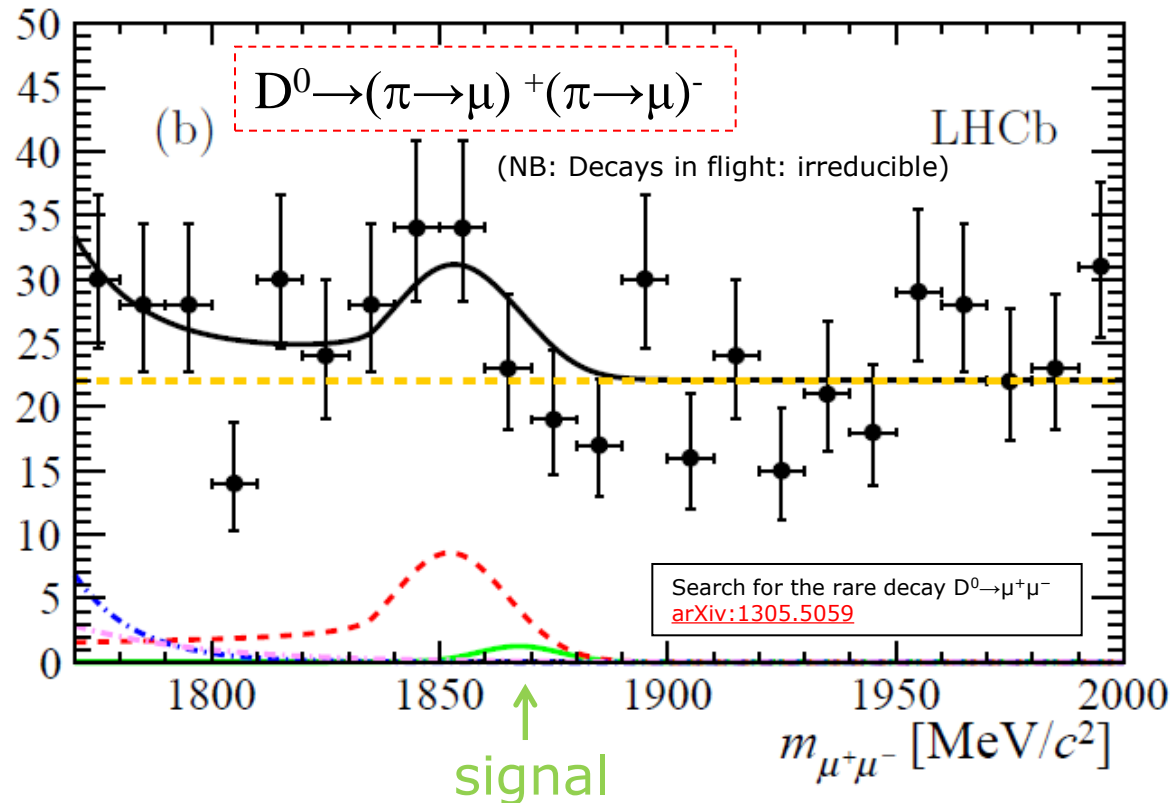
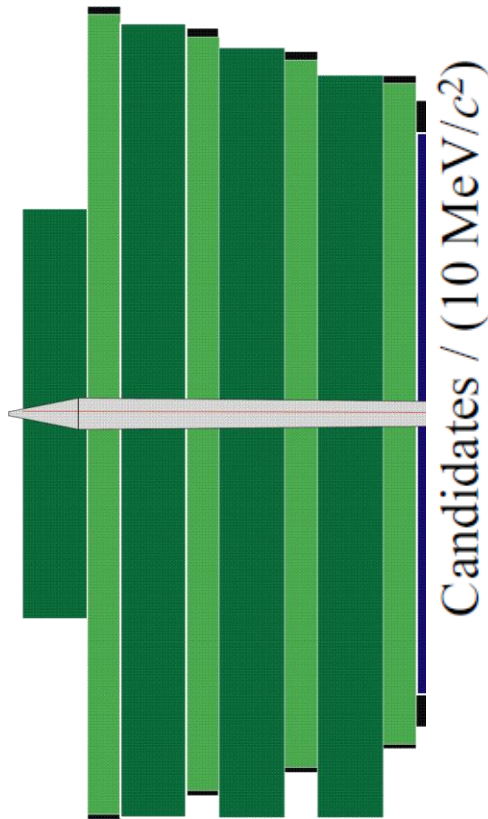


Photons in final state:



The LHCb Detector

MUON: $\varepsilon(\mu \rightarrow \mu) \sim 97\%$, $\varepsilon(\pi \rightarrow \mu) \sim 1\text{-}3\%$



Detector Performance Papers (2012+2013)

More in the pipeline

- 1) Performance of the Muon Identification at LHCb
- 2) Radiation damage in the LHCb Vertex Locator
- 3) Performance of the LHCb RICH detector at the LHC
- 4) The LHCb Trigger and its Performance in 2011
- 5) Performance of the LHCb muon system
- 6) Radiation hardness of the LHCb Outer Tracker

[arXiv:1306.0249](https://arxiv.org/abs/1306.0249)

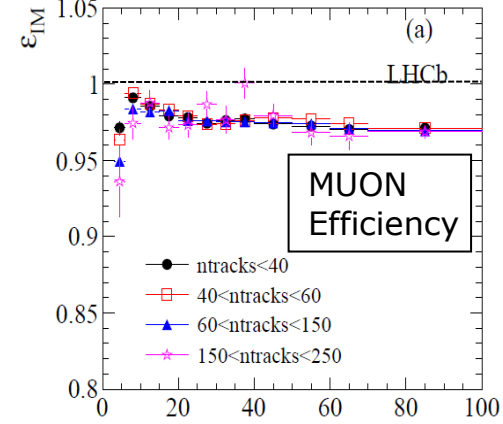
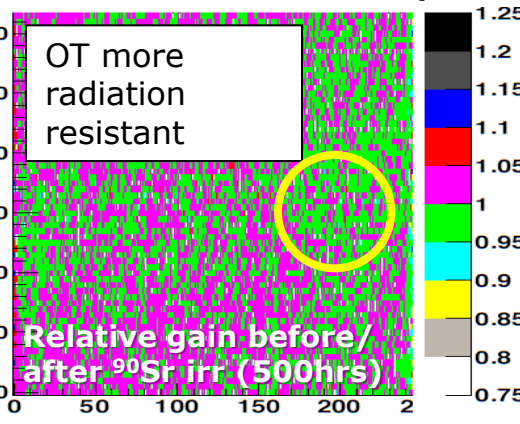
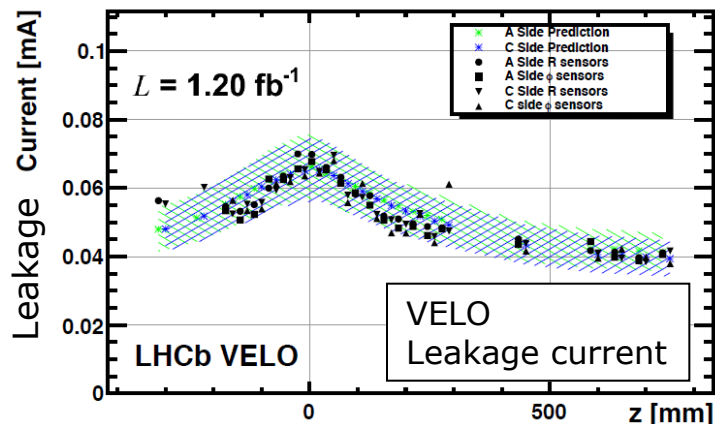
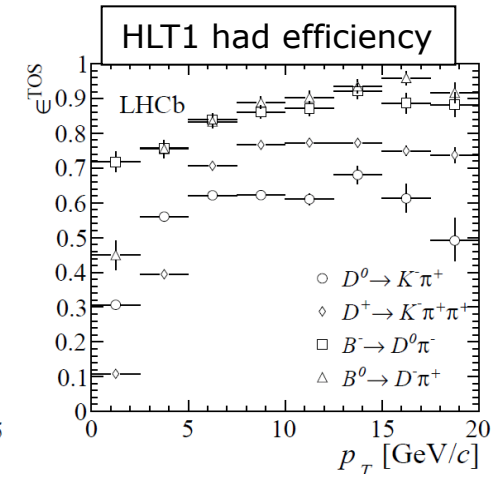
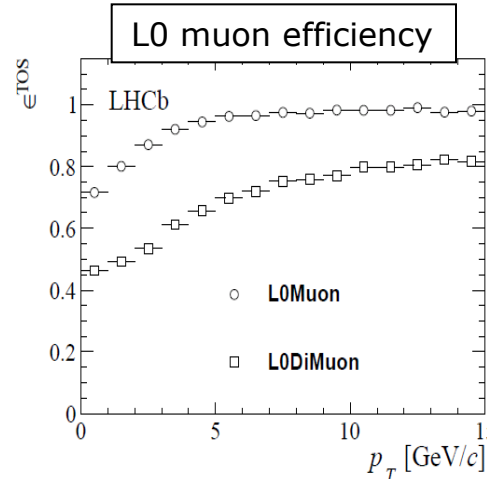
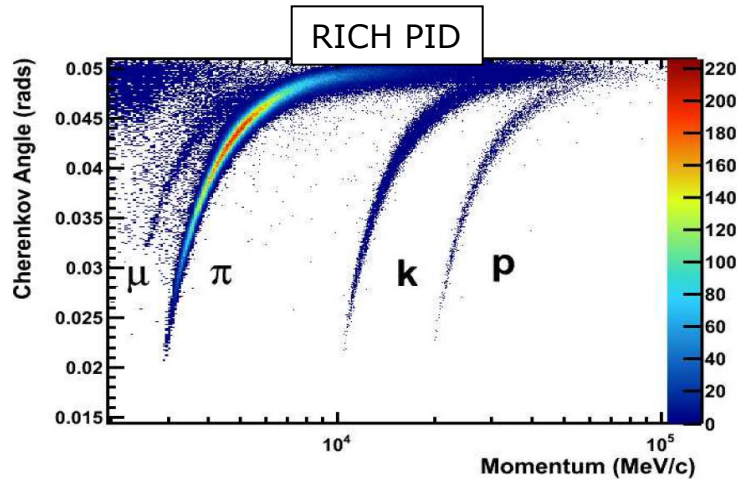
[arXiv:1302.5259](https://arxiv.org/abs/1302.5259)

[EPJ C79 \(2013\) 2431](#)

[JINST 8 \(2013\) P04022](#)

[JINST 8 \(2013\) P02022](#)

[NIM A656 \(2011\) 45](#)



Activities in LS1

Thanks to
EN-dep

- Major work on **power network** consolidation
 - Redundancy at all levels
- **Beampipe** dismantled
 - New section + lighter support
 - Special opening procedure with Neon in VELO
 - Work done over 3 months
- Online
 - Redundancy of power and cooling
 - Replacing hardware (120 disks upgraded)
- **Commissioning** week (26 May 2013):
 - full DAQ of entire LHCb operational
- **Subdetectors**:
 - MUON: Doubling HV channels
 - OT: Irradiation tests
 - CALO: Replace fibers of LED system
 - ST: Cooling consolidation

Thanks to
TE-dep



Papers published in 2013

(arXiv:130x.yyyy)

<p>[31] LHCb collaboration, R. Aaij <i>et al.</i>, LHCb-PAPER-2013-030, in preparation.</p> <p>[32] LHCb collaboration, R. Aaij <i>et al.</i>, Limits on the $B_{(s)}^0 \rightarrow J/\psi p \bar{p}$ and $B^+ \rightarrow J/\psi p \bar{p} \pi^+$ decays, LHCb-PAPER-2013-029, in preparation.</p> <p>[33] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of the relative rate of prompt χ_{c1}, χ_{c2} and χ_{c0} production at $\sqrt{s} = 7$ TeV, LHCb-PAPER-2013-028, in preparation.</p> <p>[34] LHCb collaboration, R. Aaij <i>et al.</i>, CP violation in the phase space of $B^{\pm} \rightarrow K^{\pm} \pi^+ \pi^-$ and $B^{\pm} \rightarrow K^{\pm} K^+ K^-$, LHCb-PAPER-2013-027, in preparation.</p> <p>[35] LHCb collaboration, R. Aaij <i>et al.</i>, Search for new charmed mesons in $D^+ \pi^-$, $D^0 \pi^+$ and $D^{*+} \pi^-$ final states, LHCb-PAPER-2013-026, in preparation.</p> <p>[36] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of the differential branching fraction of the decay $A_0^0 \rightarrow A \mu^+ \mu^-$, LHCb-PAPER-2013-025, in preparation.</p> <p>[37] LHCb collaboration, R. Aaij <i>et al.</i>, Observation of $B_0^0 \rightarrow \chi_{c1,2} K^0$ decay and study of $B^0 \rightarrow \chi_{c1,2} K^{*0}$ decays, LHCb-PAPER-2013-024, in preparation.</p> <p>[38] LHCb collaboration, R. Aaij <i>et al.</i>, A measurement of the polarisation amplitudes in $B^0 \rightarrow J/\psi K^{*0}(892)$ decays, LHCb-PAPER-2013-023, in preparation.</p> <p>[39] LHCb collaboration, R. Aaij <i>et al.</i>, Measurements of the branching fractions of the decays $B_s^0 \rightarrow \bar{D}^0 K^- \pi^+$ and $B^0 \rightarrow \bar{D}^0 K^+ \pi^-$, arXiv:1304.6317, submitted to Phys. Rev. D.</p> <p>[40] LHCb collaboration, R. Aaij <i>et al.</i>, Observation of $B_c^+ \rightarrow J/\psi K^+$ decay, LHCb-PAPER-2013-021, in preparation.</p> <p>[41] LHCb collaboration, R. Aaij <i>et al.</i>, A measurement of γ from a combination of $B^{\pm} \rightarrow Dh^{\pm}$ analyses, arXiv:1305.2050, submitted to Phys. Lett. B.</p> <p>[42] LHCb collaboration, R. Aaij <i>et al.</i>, Differential branching fraction and angular analysis of the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$, arXiv:1304.6325, submitted to JHEP.</p> <p>[43] LHCb collaboration, R. Aaij <i>et al.</i>, First observation of CP violation in the decays of bottom strange mesons, arXiv:1304.6173, submitted to Phys. Rev. Lett.</p> <p>[44] LHCb collaboration, R. Aaij <i>et al.</i>, Differential branching fraction and angular analysis of the decay $B_s^0 \rightarrow \phi \mu^+ \mu^-$, arXiv:1305.2168, submitted to JHEP.</p> <p>[45] LHCb collaboration, R. Aaij <i>et al.</i>, Production of J/ψ and $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ mesons at $\sqrt{s} = 8$ TeV, arXiv:1304.6977, submitted to JHEP.</p>	<p>[46] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of the $B_s^0 \rightarrow J/\psi K_S^0$ effective lifetime, arXiv:1304.4500, to appear in Nucl. Phys. B.</p> <p>[47] LHCb collaboration, R. Aaij <i>et al.</i>, Searches for violation of lepton flavour and baryon number in tau lepton decays at LHCb, arXiv:1304.4518, submitted to Phys. Lett. B.</p> <p>[48] LHCb collaboration, R. Aaij <i>et al.</i>, Search for the rare decay $D^0 \rightarrow \mu^+ \mu^-$, arXiv:1305.5059, submitted to Phys. Lett. B.</p> <p>[49] LHCb collaboration, R. Aaij <i>et al.</i>, First observation of the decay $B_s^0 \rightarrow \phi \bar{K}^{*0}$, LHCb-PAPER-2013-012, in preparation.</p> <p>[50] LHCb collaboration, R. Aaij <i>et al.</i>, Precision measurements of D meson mass differences, arXiv:1304.6865, submitted to JHEP.</p> <p>[51] LHCb collaboration, R. Aaij <i>et al.</i>, Observation of $B_c^+ \rightarrow J/\psi D_s^+$ decay, arXiv:1304.4530, submitted to Phys. Rev. D.</p> <p>[52] LHCb collaboration, R. Aaij <i>et al.</i>, Limits on neutral Higgs production in the forward region in pp collisions at $\sqrt{s} = 7$ TeV, arXiv:1304.2591, to appear in JHEP.</p> <p>[53] LHCb collaboration, R. Aaij <i>et al.</i>, J/ψ polarisation, LHCb-PAPER-2013-008, in preparation.</p> <p>[54] LHCb collaboration, R. Aaij <i>et al.</i>, First measurement of the CP-violating phase in $B_s^0 \rightarrow \phi \phi$ decays, arXiv:1303.7125, to appear in Phys. Rev. Lett.</p> <p>[55] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of the $B_s^0 - \bar{B}_s^0$ oscillation frequency Δm_s in the decay $B_s^0 \rightarrow D_s^+ \pi^-$, New J. Phys. 15 (2013) 053021, arXiv:1304.4741.</p> <p>[56] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of the $B^0 \rightarrow K^{*0} e^+ e^-$ branching fraction at low dilepton mass, arXiv:1304.3035, submitted to JHEP.</p> <p>[57] LHCb collaboration, R. Aaij <i>et al.</i>, Measurements of B meson production in pp collisions at $\sqrt{s} = 7$ TeV, LHCb-PAPER-2013-004, in preparation.</p> <p>[58] LHCb collaboration, R. Aaij <i>et al.</i>, Search for direct CP violation in $D^0 \rightarrow h^- h^+$ modes using semileptonic B decays, Phys. Lett. B723 (2013) 33, arXiv:1303.2614.</p> <p>[59] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of CP-violation and the B_0^0-meson decay width difference with $B_0^0 \rightarrow J/\psi K^+ K^-$ and $B_0^0 \rightarrow J/\psi \pi^+ \pi^-$ decays, arXiv:1304.2600, to appear in Phys. Rev. D.</p> <p>[60] LHCb collaboration, R. Aaij <i>et al.</i>, Determination of the X(3872) quantum numbers, arXiv:1302.6269, to appear in Phys. Rev. Lett.</p>	<p>[61] LHCb collaboration, R. Aaij <i>et al.</i>, Measurements of the $A_0^0 \rightarrow \Lambda J/\psi$ decay amplitudes and the Λ_b baryon production polarisation in pp collisions at $\sqrt{s} = 7$ TeV, arXiv:1302.5578, to appear in Phys. Lett. B.</p> <p>[62] LHCb collaboration, R. Aaij <i>et al.</i>, Search for the decay $B_s^0 \rightarrow D^{*+} \pi^{\pm}$, Phys. Rev. D87 (2013) 071101(R), arXiv:1302.6446.</p> <p>[63] LHCb collaboration, R. Aaij <i>et al.</i>, Observation of the suppressed ADS modes $B^{\pm} \rightarrow [\pi^{\pm} K^{\mp} \pi^+ \pi^-]_D K^{\pm}$ and $B^{\pm} \rightarrow [\pi^{\pm} K^{\mp} \pi^+ \pi^-]_D \pi^{\pm}$, Phys. Lett. B723 (2013) 44, arXiv:1303.4646.</p> <p>[64] LHCb collaboration, R. Aaij <i>et al.</i>, Observation of the decay $B_c^+ \rightarrow \psi(2S) \pi^+$, Phys. Rev. D87 (2013) 071103(R), arXiv:1303.1737.</p> <p>[65] LHCb collaboration, R. Aaij <i>et al.</i>, Observations of $B_s^0 \rightarrow \psi(2S) \eta$ and $B_{(s)}^0 \rightarrow \psi(2S) \pi^+ \pi^-$ decays, Nucl. Phys. B871 (2013) 403, arXiv:1302.6354.</p> <p>[66] LHCb collaboration, R. Aaij <i>et al.</i>, Searches for CP violation in the $D^+ \rightarrow \phi \pi^+$ and $D_s^+ \rightarrow K_S^0 \pi^+$ decays, arXiv:1303.4906, submitted to JHEP.</p> <p>[67] LHCb collaboration, R. Aaij <i>et al.</i>, A search for $D_{(s)}^+ \rightarrow \pi^+ \mu^- \mu^-$ and $D_{(s)}^+ \rightarrow \pi^- \mu^+ \mu^+$ decays, arXiv:1304.6365, submitted to Phys. Lett. B.</p> <p>[68] LHCb collaboration, R. Aaij <i>et al.</i>, First observations of $B^0 \rightarrow D^+ D^-$, $D_s^+ D^-$ and $D^0 \bar{D}^0$ decays, Phys. Rev. D87 (2013) 092007, arXiv:1302.5854.</p> <p>[69] LHCb collaboration, R. Aaij <i>et al.</i>, Search for rare $B_{(s)}^0 \rightarrow \mu \mu \mu \mu$ decays, Phys. Rev. Lett. 110 (2013) 211801, arXiv:1303.1092.</p> <p>[70] LHCb collaboration, R. Aaij <i>et al.</i>, Measurements of the Λ_b^0, Ξ_b^- and Ω_b^- baryon masses, Phys. Rev. Lett. 110 (2013) 182001, arXiv:1302.1072.</p> <p>[71] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of the branching fractions of the $B^+ \rightarrow p \bar{p} K^+$ decay channel and its charmonium contributions, arXiv:1303.7133, to appear in Eur. Phys. J. C.</p> <p>[72] LHCb collaboration, R. Aaij <i>et al.</i>, Study of $B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+$ and $B^0 \rightarrow D^{*-} K^+ \pi^- \pi^+$ decays, Phys. Rev. D87 (2013) 092001, arXiv:1303.6861.</p> <p>[73] LHCb collaboration, R. Aaij <i>et al.</i>, Analysis of the resonant components in $\bar{B}^0 \rightarrow J/\psi \pi^+ \pi^-$, Phys. Rev. D87 (2013) 052001, arXiv:1301.5347.</p> <p>[74] LHCb collaboration, R. Aaij <i>et al.</i>, Exclusive J/ψ and $\psi(2S)$ production at $\sqrt{s} = 7$ TeV, J. Phys. G40 (2013) 045001, arXiv:1301.7084.</p> <p>[75] LHCb collaboration, R. Aaij <i>et al.</i>, First evidence for the decay $B_s^0 \rightarrow \mu^+ \mu^-$, Phys. Rev. Lett. 110 (2013) 021801, arXiv:1211.2674.</p> <p>[76] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of CP observables in $B^0 \rightarrow DK^{*0}$ with $D \rightarrow K^+ K^-$, JHEP 03 (2013) 67, arXiv:1212.5205.</p> <p>[77] LHCb collaboration, R. Aaij <i>et al.</i>, Prompt charm production in pp collisions at $\sqrt{s} = 7$ TeV, Nucl. Phys. B871 (2013) 1, arXiv:1302.2864.</p> <p>[78] LHCb collaboration, R. Aaij <i>et al.</i>, Amplitude analysis and branching fraction measurement of $\bar{B}_s^0 \rightarrow J/\psi K^+ K^-$, Phys. Rev. D87 (2013) 072004, arXiv:1302.1213.</p> <p>[81] LHCb collaboration, R. Aaij <i>et al.</i>, Measurement of the fragmentation fraction ratio f_u/f_d and its dependence on B meson kinematics, JHEP 04 (2013) 1, arXiv:1301.5286.</p>
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2013:

- 37 submitted

Total (2010 – 2013):

- 104 published
- 13 approved
- 6 submitted

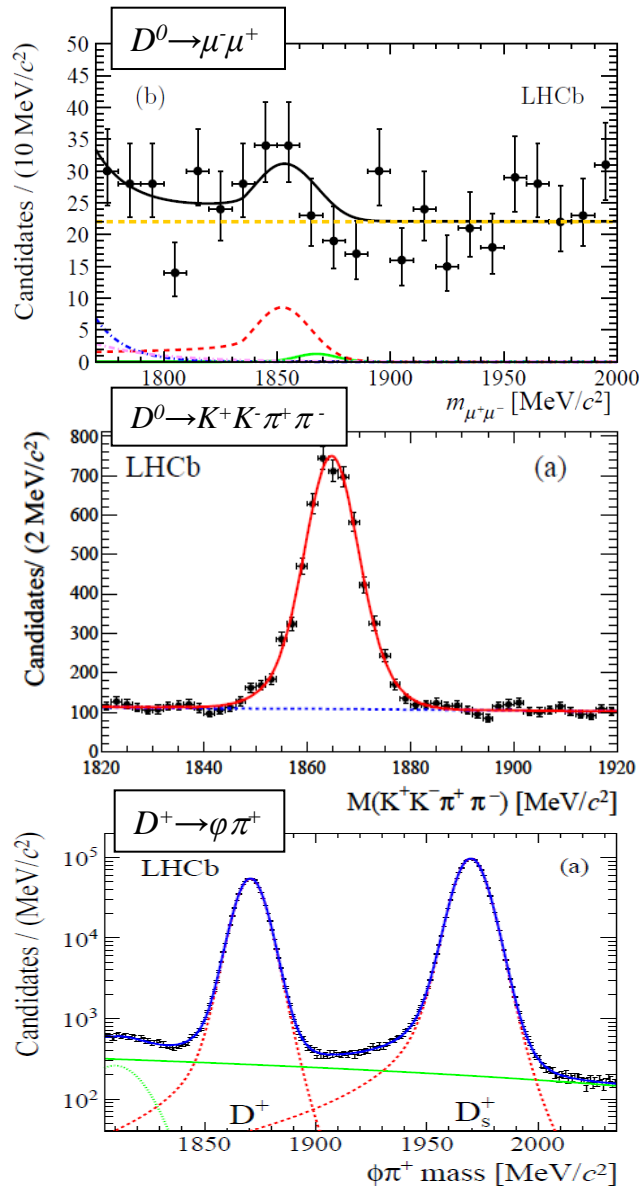
Papers submitted since last LHCC (13 Mar 2013):

- 1) Observation of $B_s^0 \rightarrow \chi_{c1} \phi$ decay and study of $B^0 \rightarrow \chi_{c1,2} K^{*0}$ decays [arXiv:1305.6511](#)
- 2) Search for the rare decay $D^0 \rightarrow \mu^+ \mu^-$ [arXiv:1305.5059](#)
- 3) Differential branching fraction and angular analysis of the decay $B_s^0 \rightarrow \phi \mu^+ \mu^-$ [arXiv:1305.2168](#)
- 4) Measurement of the CKM angle γ from a combination of $B \rightarrow Dh$ analyses [arXiv:1305.2050](#)
- 5) Production of J/ψ and Y mesons in pp collisions at $\sqrt{s} = 8$ TeV [arXiv:1304.6977](#)
- 6) Precision measurement of D meson mass differences [arXiv:1304.6865](#)
- 7) Search for $D^+_{(s)} \rightarrow \pi^+ \mu^+ \mu^-$ and $D^+_{(s)} \rightarrow \pi^- \mu^+ \mu^-$ decays [arXiv:1304.6365](#)
- 8) Differential branching fraction and angular analysis of the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ [arXiv:1304.6325](#)
- 9) Measurement of the branching fractions of the decays $B_s^0 \rightarrow D^{0-} K^- \pi^+$ and $B^0 \rightarrow D^{0-} K^+ \pi^-$ [arXiv:1304.6317](#)
- 10) First observation of CP violation in the decays of B_s mesons [arXiv:1304.6173](#)
- 11) Precision measurement of the $B_s^0 - B_s^{0-}$ oscillation frequency with the decay $B_s^0 \rightarrow D_s^- \pi^+$ [arXiv:1304.4741](#)
- 12) Observation of $B^+_c \rightarrow J/\psi D^+_s$ and $B^+_c \rightarrow J/\psi D^{*+}_s$ decays [arXiv:1304.4741](#)
- 13) Searches for violation of lepton flavour and baryon number in tau lepton decays at LHCb [arXiv:1304.4518](#)
- 14) Measurement of the effective $B_s^0 \rightarrow J/\psi K_S^0$ lifetime [arXiv:1304.4500](#)
- 15) Measurement of the $B^0 \rightarrow K^{*0} e^+ e^-$ branching fraction at low dilepton mass [arXiv:1304.3035](#)
- 16) Measurement of CP violation and the B_s^0 meson decay width difference with $B_s^0 \rightarrow J/\psi K^+ K^-$ and $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ decays [arXiv:1304.2600](#)
- 17) Limits on neutral Higgs boson production in the forward region in pp collisions at $\sqrt{s} = 7$ TeV [arXiv:1304.2591](#)
- 18) Measurements of the branching fractions of $B^+ \rightarrow \rho^+ K^+$ decays [arXiv:1303.7133](#)
- 19) First measurement of the CP-violating phase in $B_s^0 \rightarrow \phi \phi$ decays [arXiv:1303.7125](#)
- 20) Study of $B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+$ and $B^0 \rightarrow D^{*-} K^+ \pi^- \pi^+$ decays [arXiv:1303.6861](#)
- 21) Search for CP violation in $D^+ \rightarrow \phi \pi^+$ and $D_s^+ \rightarrow K_S \pi^+$ decays [arXiv:1303.4906](#)
- 22) Observation of the suppressed ADS modes $B^\pm \rightarrow [\pi^\pm K^\mp \pi^+ \pi^-] DK^\pm$ and $B^\pm \rightarrow [\pi^\pm K^\mp \pi^+ \pi^-] D \pi^\pm$ [arXiv:1303.4646](#)
- 23) Search for direct CP violation in $D^0 \rightarrow h^- h^+$ modes using semileptonic B decays [arXiv:1303.2614](#)

Papers submitted since last LHCC (13 Mar 2013):

- 1) Observation of $B^0_s \rightarrow \chi_{c1} \phi$ decay and study of $B^0 \rightarrow \chi_{c1,2} K^{*0}$ decays [arXiv:1305.6511](#)
- 2) Search for the rare decay $D^0 \rightarrow \mu^+ \mu^-$ [arXiv:1305.5059](#)
- 3) Differential branching fraction and angular analysis of the decay $B^0_s \rightarrow \phi \mu^+ \mu^-$ [arXiv:1305.2168](#)
- 4) Measurement of the CKM angle γ from a combination of $B \rightarrow Dh$ analyses** [arXiv:1305.2050](#)
- 5) Production of J/ψ and Y mesons in pp collisions at $\sqrt{s} = 8$ TeV [arXiv:1304.6977](#)
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- 7) Search for $D^+_{(s)} \rightarrow \pi^+ \mu^+ \mu^-$ and $D^+_{(s)} \rightarrow \pi^- \mu^+ \mu^+$ decays [arXiv:1304.6365](#)
- 8) Differential branching fraction and angular analysis of the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$** [arXiv:1304.6325](#)
- 9) Measurement of the branching fractions of the decays $B^0_s \rightarrow D^{0-} K^- \pi^+$ and $B^0 \rightarrow D^{0-} K^+ \pi^-$ [arXiv:1304.6317](#)
- 10) First observation of CP violation in the decays of B_s mesons** [arXiv:1304.6173](#)
- 11) Precision measurement of the B^0_s - B^{*0}_s oscillation frequency with the decay $B^0_s \rightarrow D^{*-}_s \pi^+$** [arXiv:1304.4741](#)
- 12) Observation of $B^+_{(c)} \rightarrow J/\psi D^+_{(s)}$ and $B^+_{(c)} \rightarrow J/\psi D^+_{(s)} K^+$ decays [arXiv:1304.4741](#)
- 13) Searches for violation of lepton flavour and baryon number in tau lepton decays at LHCb [arXiv:1304.4518](#)
- 14) Measurement of the effective $B^0_s \rightarrow J/\psi K^0_S$ lifetime [arXiv:1304.4500](#)
- 15) Measurement of the $B^0 \rightarrow K^{*0} e^+ e^-$ branching fraction at low dilepton mass [arXiv:1304.3035](#)
- 16) Measurement of CP violation and the B^0_s meson decay width difference with $B^0_s \rightarrow J/\psi K^+ K^-$ and $B^0_s \rightarrow J/\psi \pi^+ \pi^-$ decays** [arXiv:1304.2600](#)
- 17) Limits on neutral Higgs boson production in the forward region in pp collisions at $\sqrt{s} = 7$ TeV [arXiv:1304.2591](#)
- 18) Measurements of the branching fractions of $B^+ \rightarrow \rho^+ K^+$ decays [arXiv:1303.7133](#)
- 19) First measurement of the CP-violating phase in $B^0_s \rightarrow \phi \phi$ decays [arXiv:1303.7125](#)
- 20) Study of $B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+$ and $B^0 \rightarrow D^{*-} K^+ \pi^- \pi^+$ decays [arXiv:1303.6861](#)
- 21) Search for CP violation in $D^+ \rightarrow \phi \pi^+$ and $D^+_s \rightarrow K^0_S \pi^+$ decays [arXiv:1303.4906](#)
- 22) Observation of the suppressed ADS modes $B^\pm \rightarrow [\pi^\pm K^\mp \pi^+ \pi^-] DK^\pm$ and $B^\pm \rightarrow [\pi^\pm K^\mp \pi^+ \pi^-] D \pi^\pm$ [arXiv:1303.4646](#)
- 23) Search for direct CP violation in $D^0 \rightarrow h^- h^+$ modes using semileptonic B decays [arXiv:1303.2614](#)

Precision physics in the charm sector

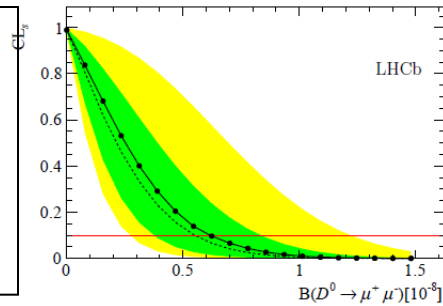


1) Rare decays

[arXiv:1305.5059](https://arxiv.org/abs/1305.5059)

$$\text{BR}(D^0 \rightarrow \mu^+ \mu^-) < 7.6 \times 10^{-9} \text{ (@ 95\% CL)}$$

➤ Best limit, x20 improvement



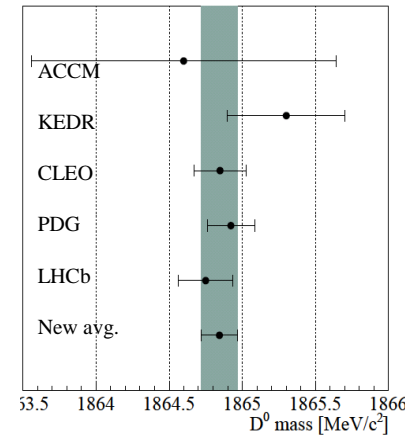
2) Masses

[arXiv:1304.6865](https://arxiv.org/abs/1304.6865)

$$M(D^0) = 1864.75 \pm 0.15 \pm 0.11 \text{ MeV}$$

$$M(D_s^+) = 1968.19 \pm 0.20 \pm 0.14 \pm 0.08 \text{ MeV}$$

- Same precision as CLEO measurement
- Important to understand X(3872)
- Used for best $m(B_c^+)$ measurement



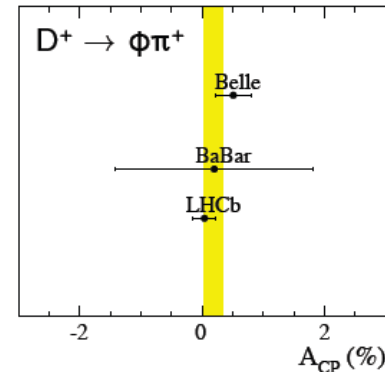
3) CP asymmetries

[arXiv:1303.4906](https://arxiv.org/abs/1303.4906)

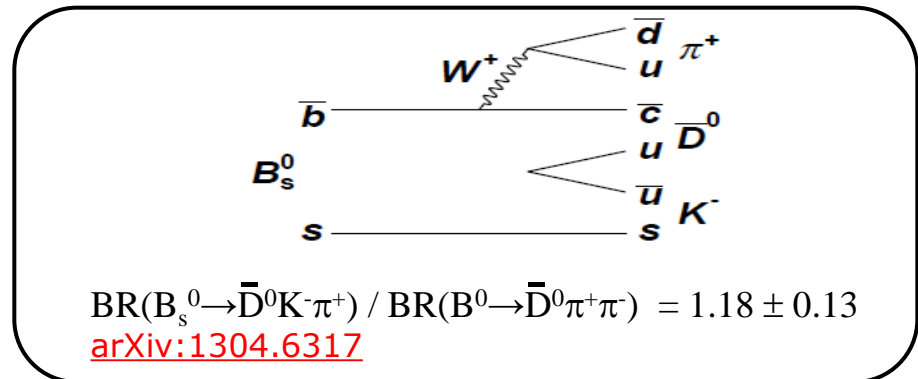
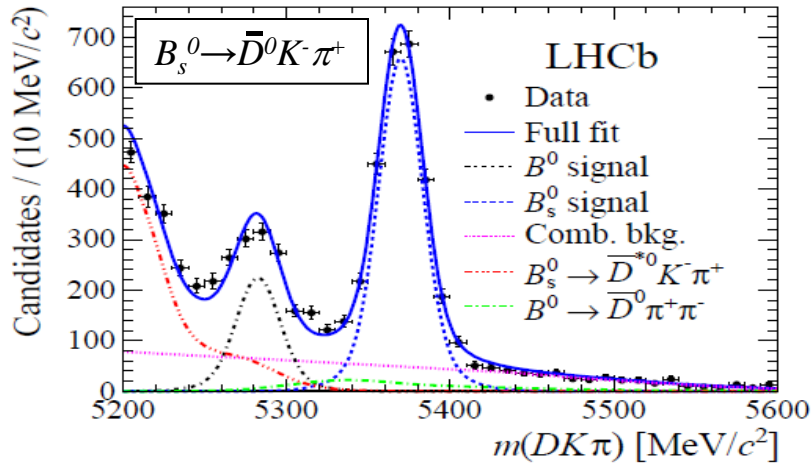
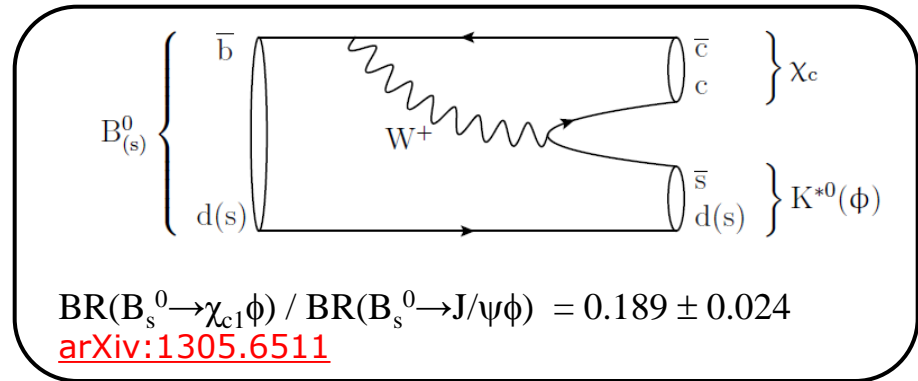
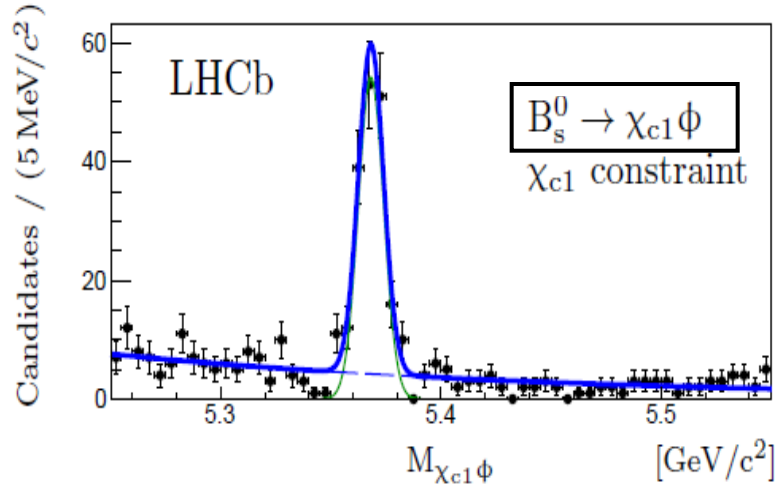
$$A_{\text{CP}}(D^+ \rightarrow \phi \pi^+) = -0.04 \pm 0.14 \pm 0.13$$

$$A_{\text{CP}}(D_s^+ \rightarrow K_S^0 \pi^+) = -0.64 \pm 0.83 \pm 0.13$$

- Most precise measurement
- No evidence for CP violation



Study large variety of bottom decays



This is what LHCb was built for!

- 1) Measurement of the CKM angle γ from a combination of $B \rightarrow Dh$ analyses [arXiv:1305.2050](#)
- 2) Differential branching fraction and angular analysis of the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ [arXiv:1304.6325](#)
- 3) First observation of CP violation in the decays of B_s mesons [arXiv:1304.6173](#)
- 4) Precision measurement of the $B_s^0 - \bar{B}_s^0$ oscillation frequency with the decay $B_s^0 \rightarrow D_s^- \pi^+$ [arXiv:1304.4741](#)
- 5) Measurement of CP violation and the B_s^0 meson decay width difference with $B_s^0 \rightarrow J/\psi K^+ K^-$ and $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ decays [arXiv:1304.2600](#)

- Unitarity angle:
- Forward backward asymmetry:
- Direct CP violation in the B_s^0 system
- B_s^0 oscillations:
- Time dependent CP violation in B_s^0

 γ A_{FB} CPV Δm_s ϕ_s

Shown last LHCC,
and now published

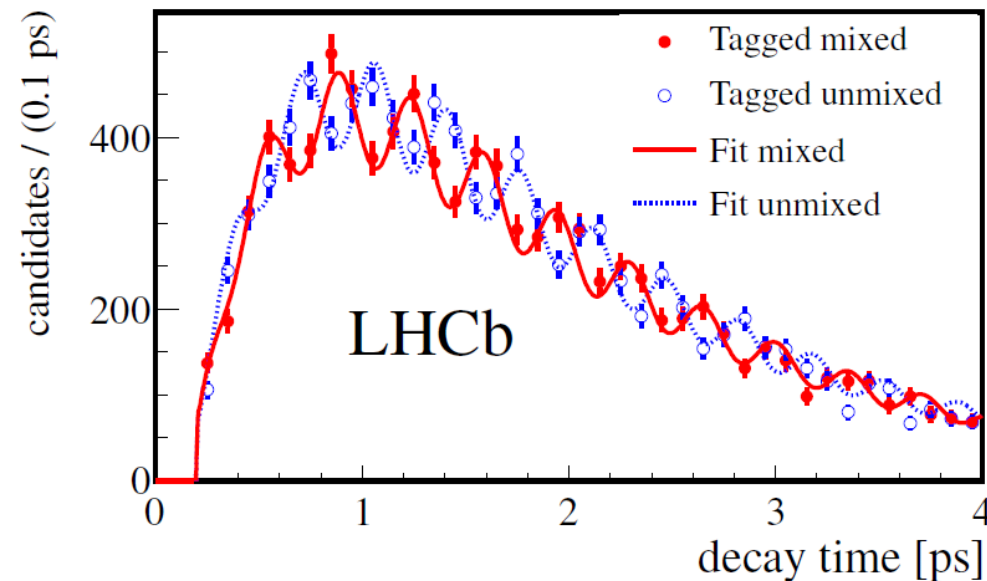
B_s^0 mixing

- B_s^0 oscillations:
- Time dependent CP violation in B_s^0

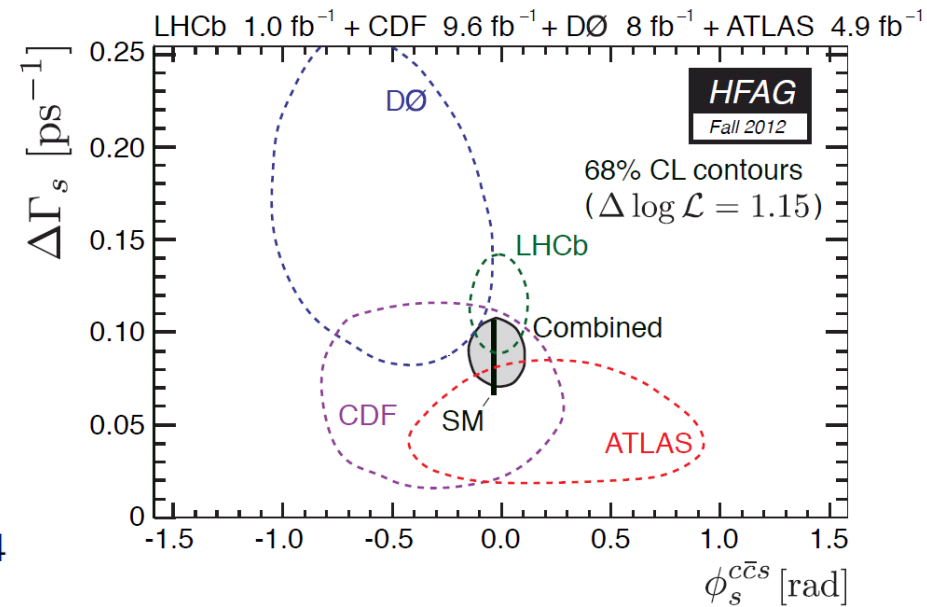
Δm_s
 ϕ_s

Shown last LHCC, and now published

$$B_s^0 \rightarrow D^-_s \pi^+$$



$$B_s^0 \rightarrow J/\psi \phi$$



Determination of γ

1) Measurement of the CKM angle γ from a combination of $B \rightarrow Dh$ analyses

[arXiv:1305.2050](#)

• Related, recent, studies:

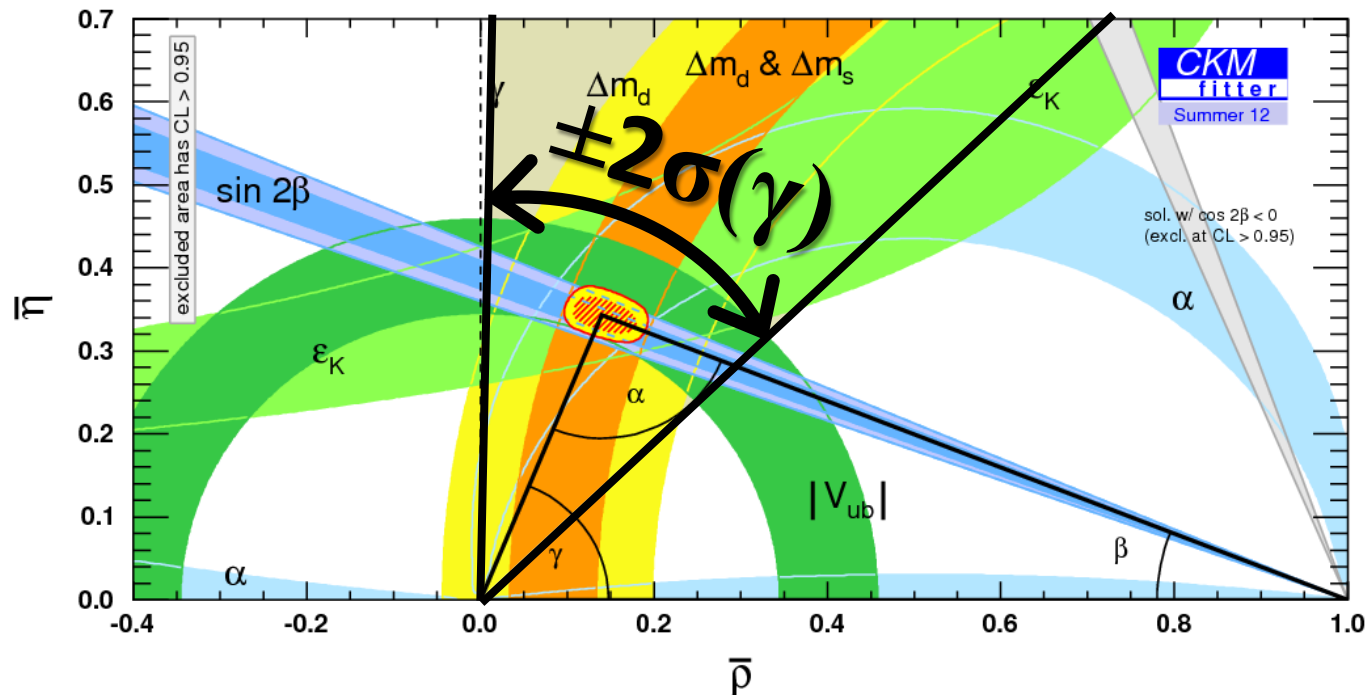
- Observation of the suppressed ADS modes $B^\pm \rightarrow [\pi^\pm K^\mp \pi^+ \pi^-] DK^\pm$ and $B^\pm \rightarrow [\pi^\pm K^\mp \pi^+ \pi^-] D\pi^\pm$
- Improved constraints on γ from $B^\pm \rightarrow DK^\pm$ decays including first results on 2012 data
- Model-independent measurement of CP violation parameters in $B^\pm \rightarrow (K^0_S h^+ h^-)_D K^\pm$ decays

[arXiv:1303.4646](#)

[LHCb-CONF-2013-006](#)

[LHCb-CONF-2013-004](#)

• Least known angle in unitarity triangle:



Determination of γ

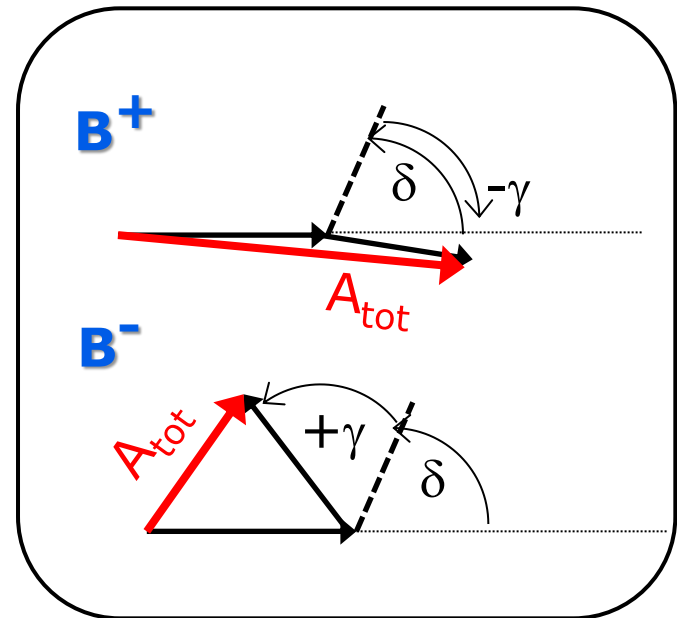
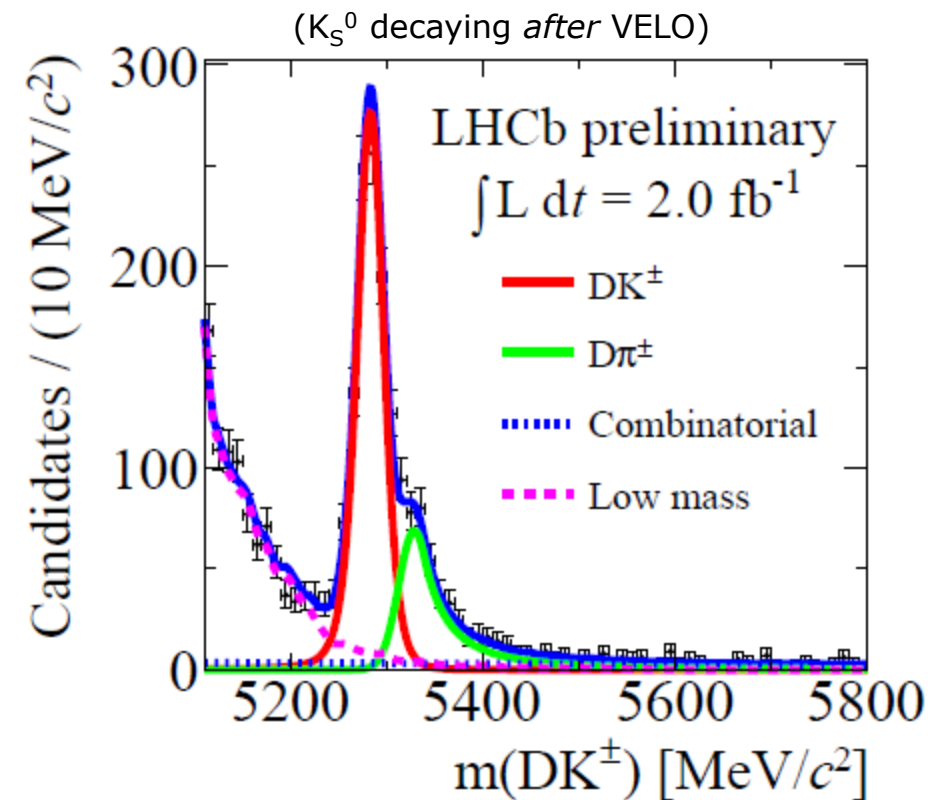
1) Measurement of the CKM angle γ from a combination of $B \rightarrow Dh$ analyses

[arXiv:1305.2050](#)

- Model-independent measurement of CP violation parameters in $B^\pm \rightarrow (K_S^0 h^\pm h^\mp)_D K^\pm$ decays

[LHCb-CONF-2013-004](#)

- Relative weak phase of two amplitudes in $B^\pm \rightarrow DK^\pm$ decays: γ
- Compare $B^- \rightarrow D(K_S^0 \pi^+ \pi^-) K^-$ with $B^+ \rightarrow D(K_S^0 \pi^+ \pi^-) K^+$



"How can a complex number affect the total amplitude?"

Determination of γ

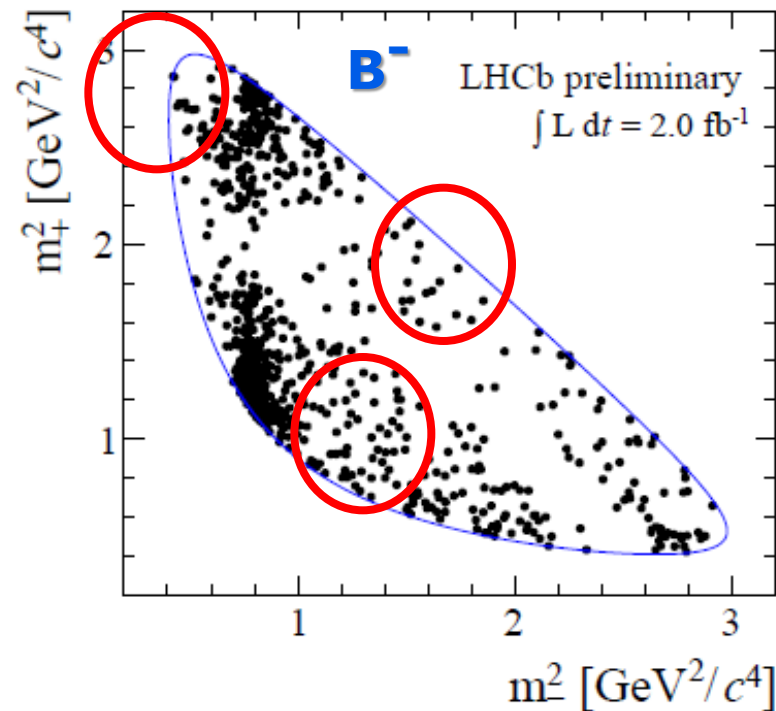
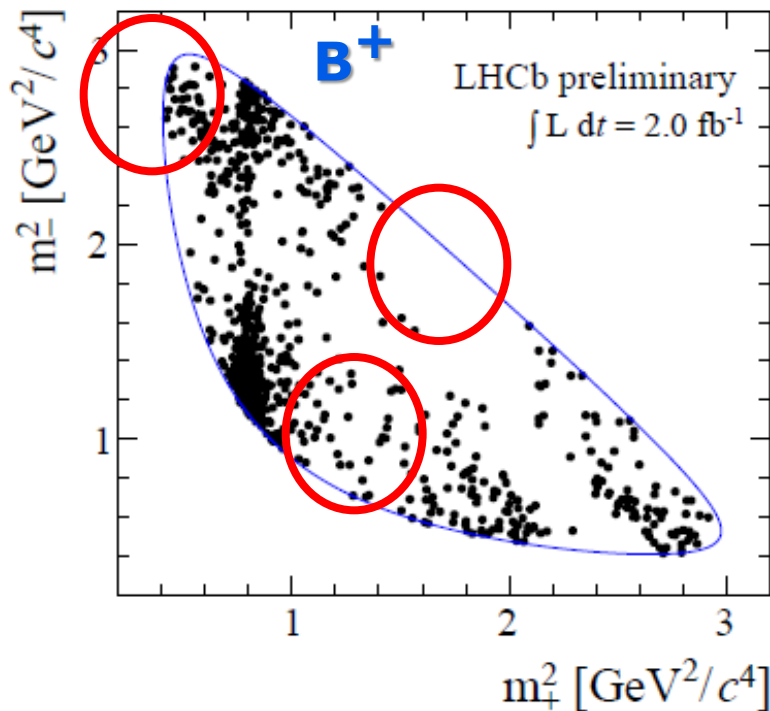
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[LHCb-CONF-2013-004](#)

- Relative weak phase of two amplitudes in $B^\pm \rightarrow DK^\pm$ decays: γ
- Compare $B^- \rightarrow D(K_S^0 \pi^+ \pi^-) K^-$ with $B^+ \rightarrow D(K_S^0 \pi^+ \pi^-) K^+$
- Best when done separately in regions of $(K_S^0 \pi^+ \pi^-)$ Dalitz plane:



Determination of γ

1) Measurement of the CKM angle γ from a combination of $B \rightarrow Dh$ analyses

[arXiv:1305.2050](#)

- Improved constraints on γ from $B^\pm \rightarrow DK^\pm$ decays including first results on 2012 data

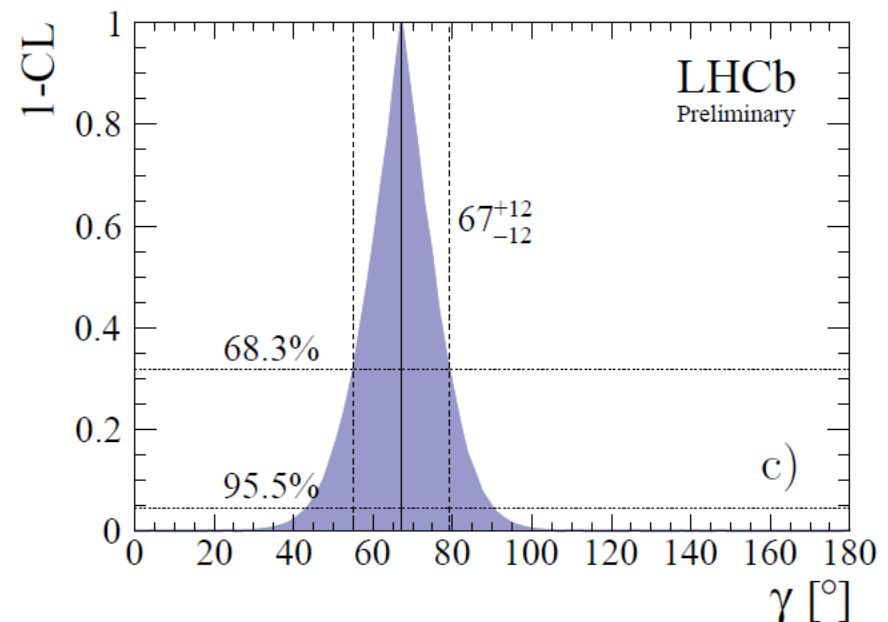
[LHCb-CONF-2013-006](#)

- Relative weak phase of two amplitudes in $B^\pm \rightarrow DK^\pm$ decays: γ
- Combine 4 measurements (with CLEO input) to determine γ
 - $B^\pm \rightarrow D(K_S^0 \pi^+ \pi^-) K^\pm$ (2 fb $^{-1}$, "GGSZ") [LHCb-CONF-2013-004](#)
 - $B^\pm \rightarrow D(K_S^0 \pi^+ \pi^-) K^\pm$ (1 fb $^{-1}$, "GGSZ") LHCb, [PL B718 \(2012\) 43](#)
 - $B^\pm \rightarrow D(h^+ h^-) K^\pm$ (1 fb $^{-1}$, "ADS" & "GLW") LHCb, [PL B712 \(2012\) 203](#)
 - $B^\pm \rightarrow D(\pi^+ K^- \pi^+ \pi^-) K^\pm$ (1 fb $^{-1}$, "ADS") LHCb, [PL B723 \(2013\) 44](#)

$$\gamma = (67 \pm 12)^\circ \text{ at } 68\% \text{ CL}$$

Comparison	γ	$\pm 1\sigma$
Belle	68	$^{+15}_{-14}$
BaBar	69	$^{+17}_{-16}$
LHCb	67	± 12

- With all data analyzed, foresee a precision of $\sim 7^\circ$





**LHCb: a place to
find penguins**

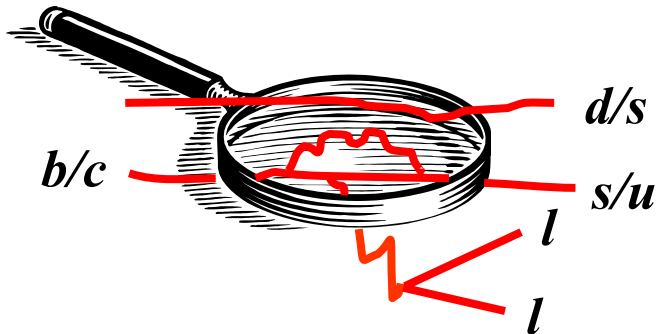
Electroweak penguins ($B^0 \rightarrow K^{*0} \mu^+ \mu^-$ and friends)

2) Differential branching fraction and angular analysis of the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

[arXiv:1304.6325](#)

- Many EW penguin decays studied:

- Differential branching fraction and angular analysis of the decay $B_s^0 \rightarrow \phi \mu^+ \mu^-$ [arXiv:1305.2168](#)
- Search for $D_{(s)}^+ \rightarrow \pi^+ \mu^+ \mu^-$ and $D_{(s)}^+ \rightarrow \pi^- \mu^+ \mu^+$ decays [arXiv:1304.6365](#)
- Measurement of the $B^0 \rightarrow K^{*0} e^+ e^-$ branching fraction at low dilepton mass [arXiv:1304.3035](#)



- Very rich “laboratory” !
- Many decays & observables
- New particles affect couplings
 - Modify SM couplings, like C_7, C_9, C_{10}
 - Add righthanded couplings, like C'_7, C'_9, C'_{10}
 - Add other couplings, like $C^{(\gamma)}_S, C^{(\gamma)}_P$
- Large variety of possible modifications to observations!

$$\mathcal{H}_{\text{eff}} = -G_F \cdot \alpha / \sqrt{2\pi} \cdot V_{tb} V_{ts}^* \sum_i (C_i \mathcal{O}_i + C'_i \mathcal{O}'_i)$$

Electroweak penguins

Differential branching fraction and angular analysis of the decay $B^0_s \rightarrow \phi \mu^+ \mu^-$

[arXiv:1305.2168](#)

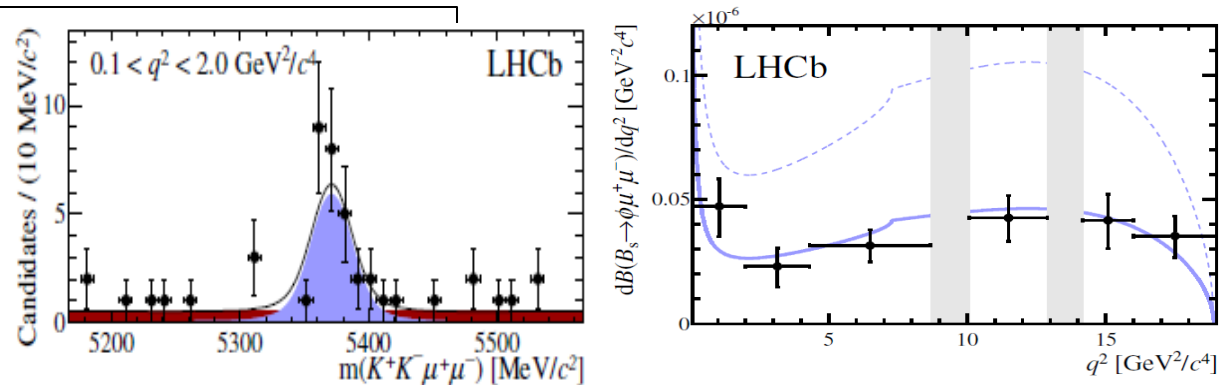
Search for $D^+_{(s)} \rightarrow \pi^+ \mu^+ \mu^-$ and $D^+_{(s)} \rightarrow \pi^- \mu^+ \mu^+$ decays

[arXiv:1304.6365](#)

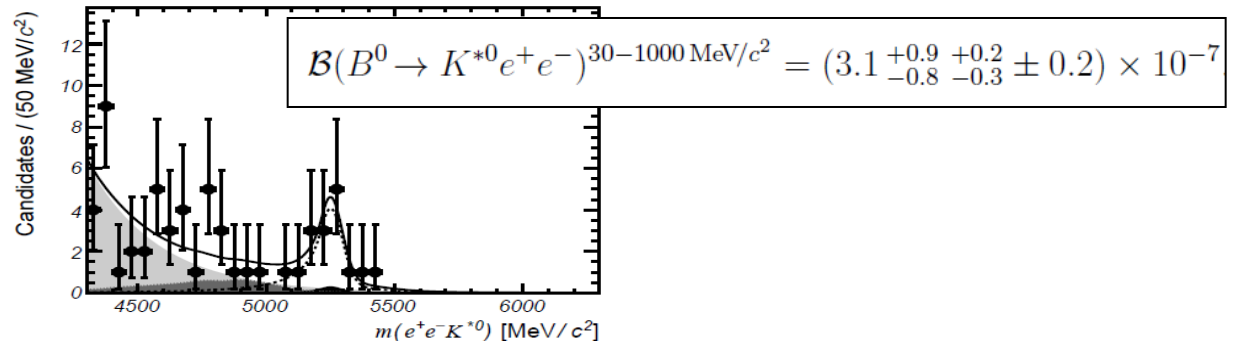
Measurement of the $B^0 \rightarrow K^{*0} e^+ e^-$ branching fraction at low dilepton mass

[arXiv:1304.3035](#)

- $B^0_s \rightarrow \phi \mu^+ \mu^-$
 - Angular analysis



- $B^0 \rightarrow K^{*0} e^+ e^-$
 - Sensitive to C_7



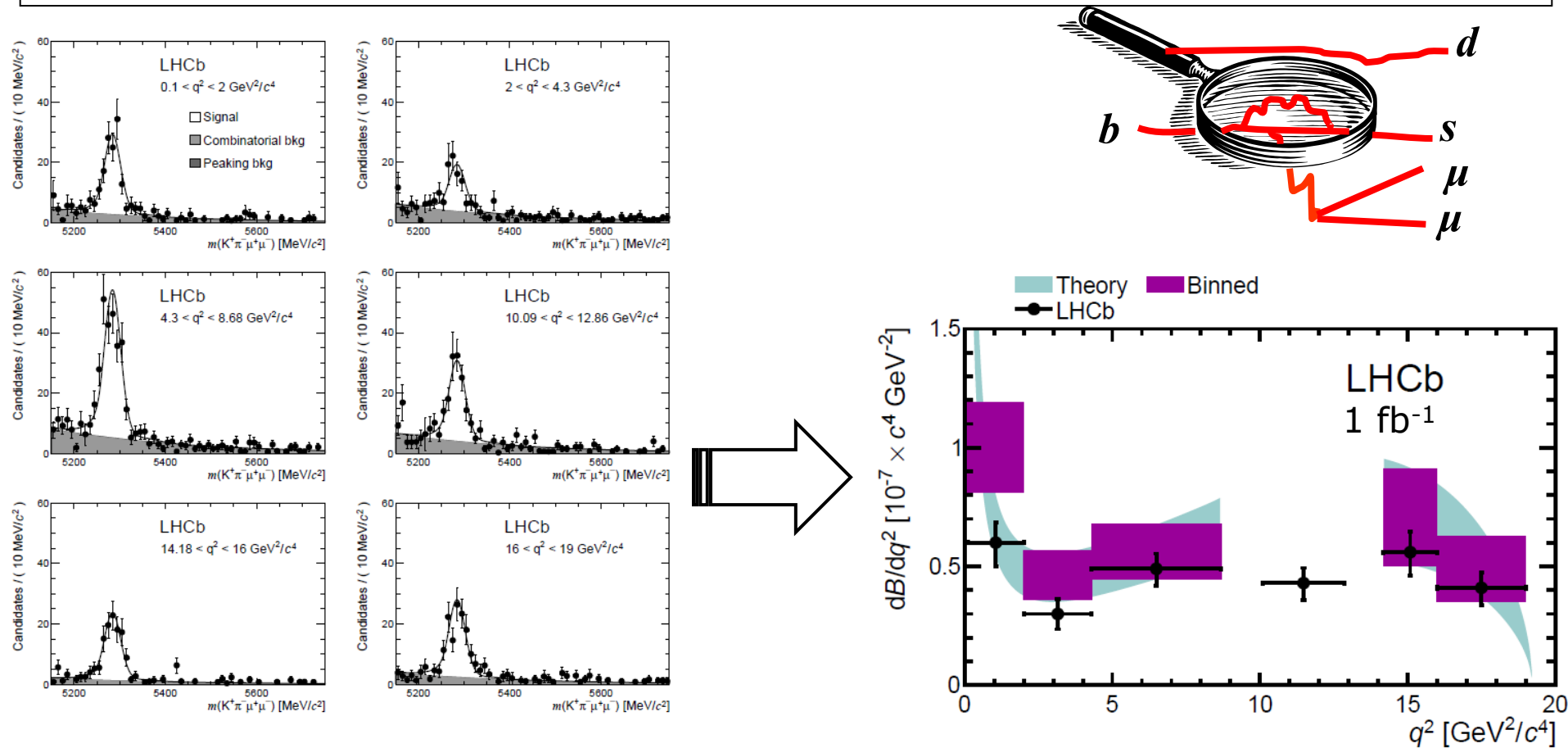
- $D^+_{(s)} \rightarrow \pi^+ \mu^+ \mu^-$
 - Limits x100 more stringent than existing
- 1) $D^+ \rightarrow \pi^+ \mu^+ \mu^-$: FCNC
 - 2) $D^+_{(s)} \rightarrow \pi^+ \mu^+ \mu^-$: Weak annihilation
 - 3) $D^+_{(s)} \rightarrow \pi^- \mu^+ \mu^+$: Lepton number violation

$$\begin{aligned} \mathcal{B}(D^+ \rightarrow \pi^+ \mu^+ \mu^-) &< 7.3 (8.3) \times 10^{-8} \\ \mathcal{B}(D^+_{(s)} \rightarrow \pi^+ \mu^+ \mu^-) &< 4.1 (4.8) \times 10^{-7} \\ \mathcal{B}(D^+ \rightarrow \pi^- \mu^+ \mu^+) &< 2.2 (2.5) \times 10^{-8} \\ \mathcal{B}(D^+_{(s)} \rightarrow \pi^- \mu^+ \mu^+) &< 1.2 (1.4) \times 10^{-7} \end{aligned}$$

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

2) Differential branching fraction and angular analysis of the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

arXiv:1304.6325

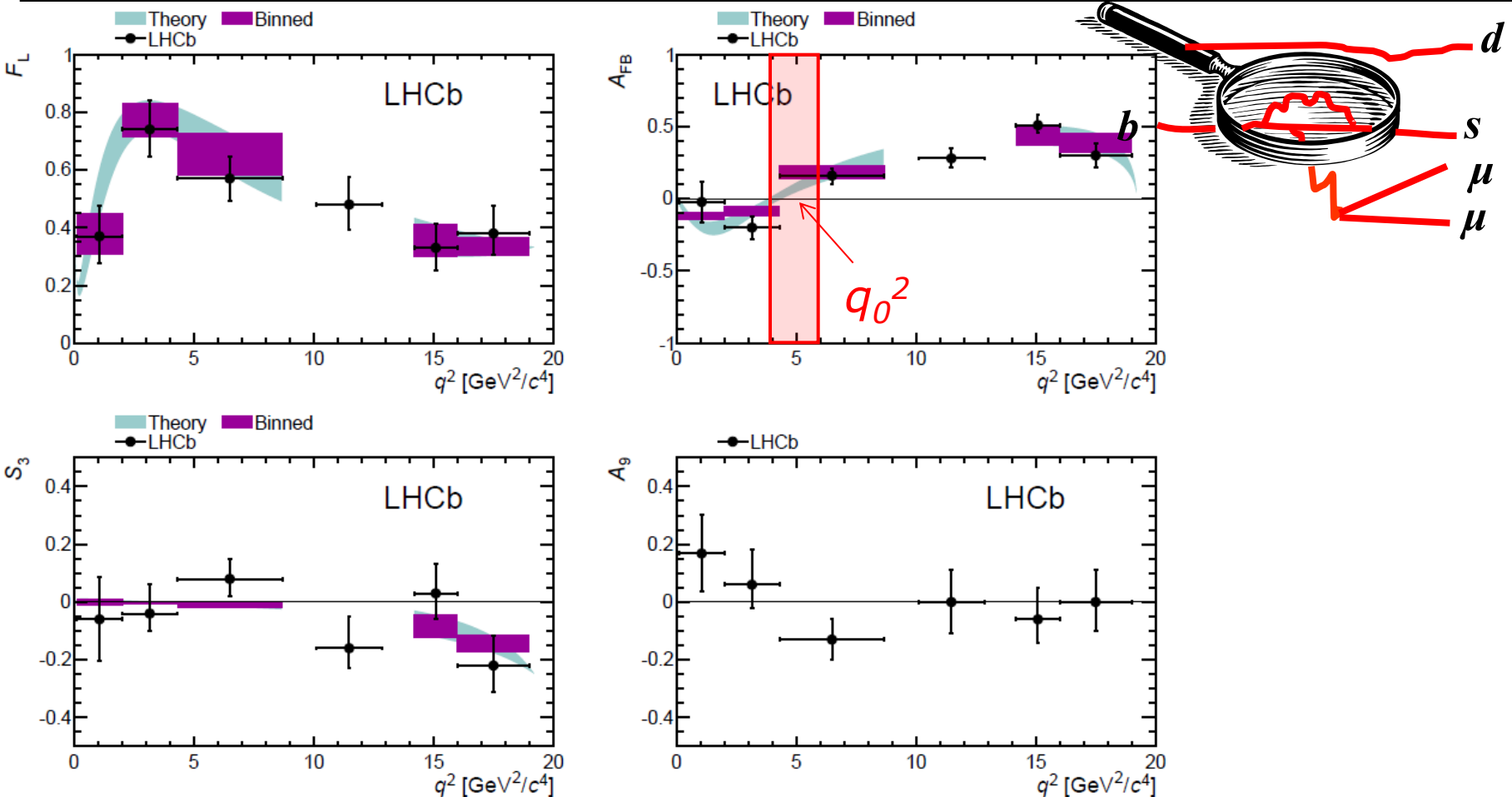


- Accurate measurement of $d\Gamma/dq^2$
- In agreement with SM

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

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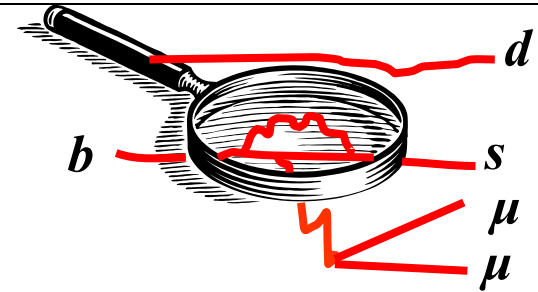
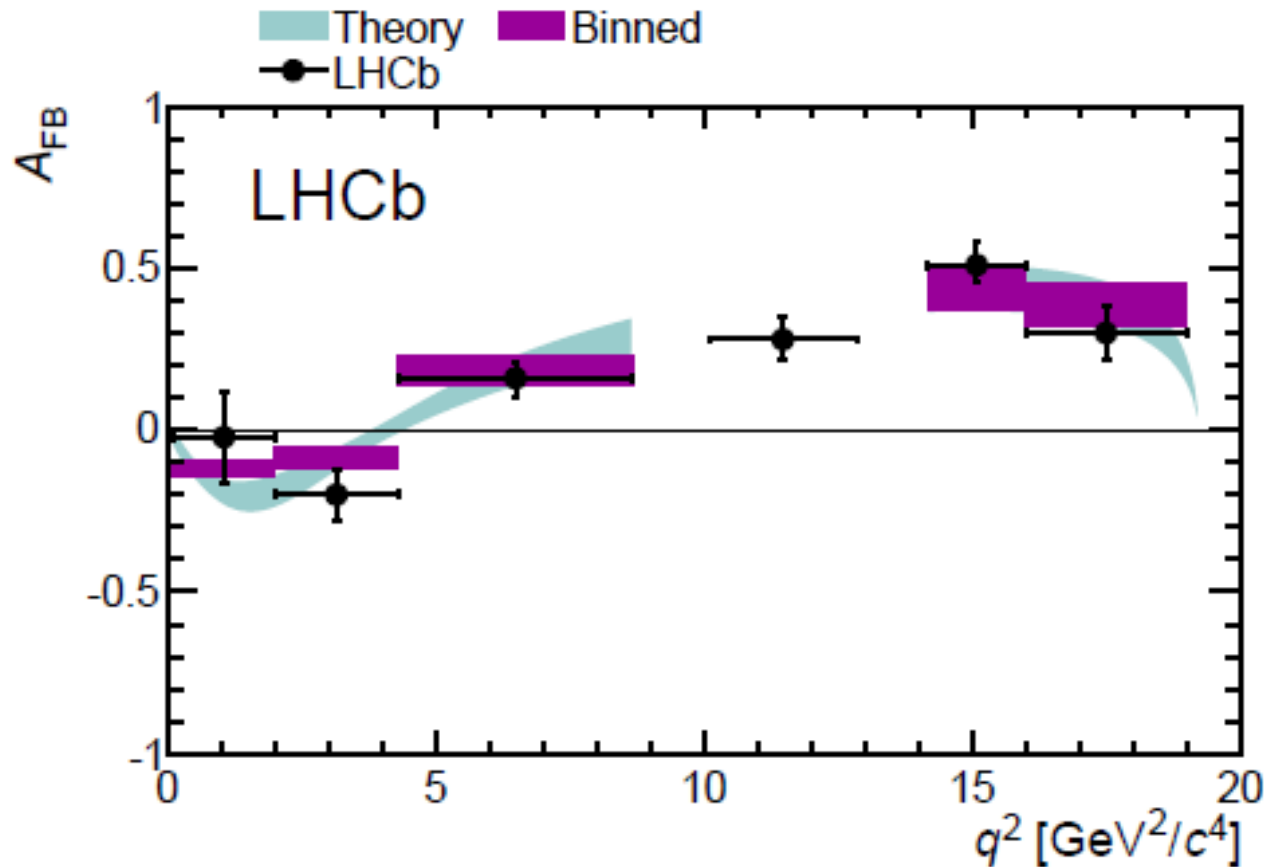


- In agreement with SM, $q_0^2 = 4.9 \pm 0.9$ GeV² (SM: 3.9 – 4.3 GeV²)
- More angular observables in the pipeline: stay tuned

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

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[arXiv:1304.6325](https://arxiv.org/abs/1304.6325)

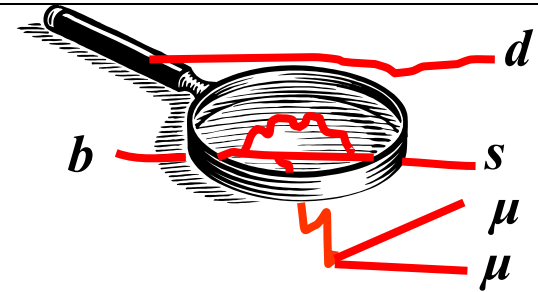
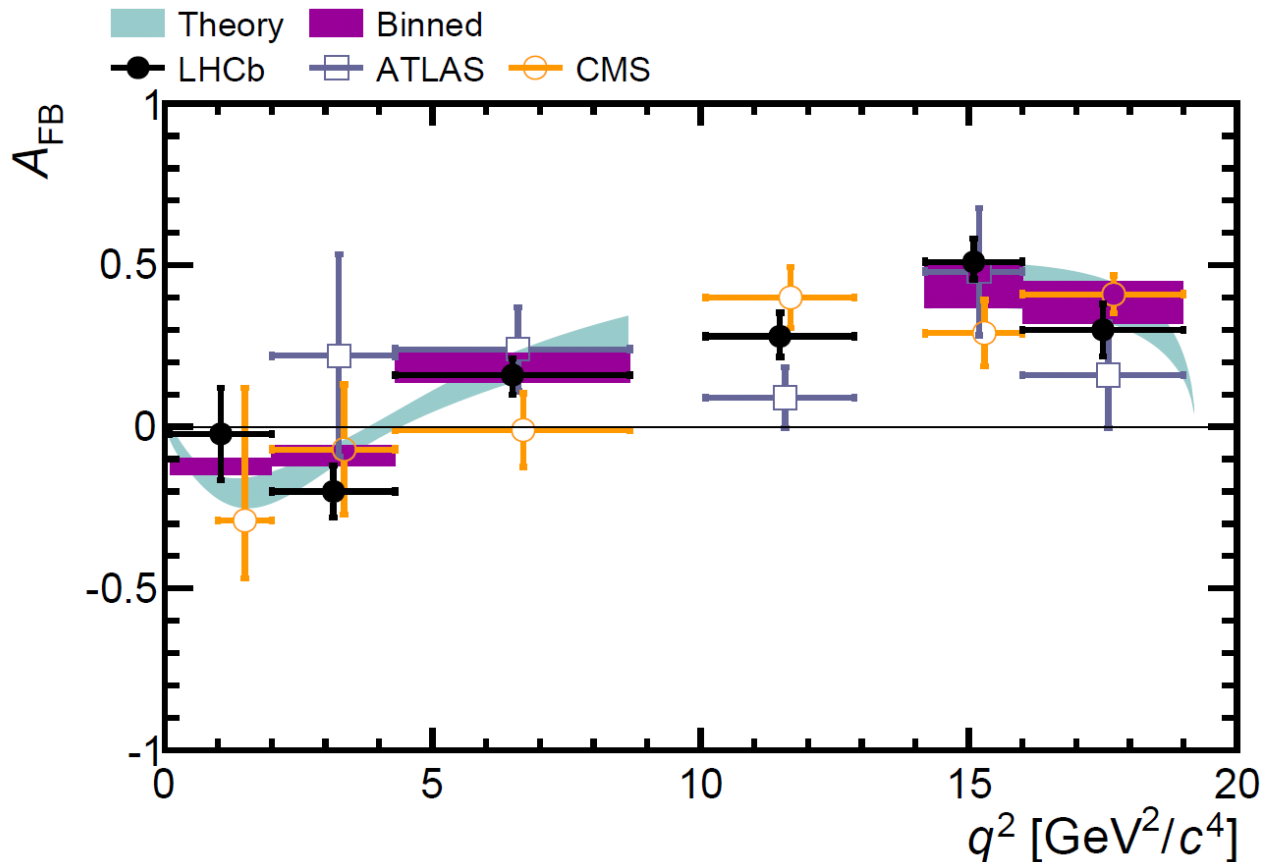


➤ In agreement with B-factories, CDF, ATLAS and CMS

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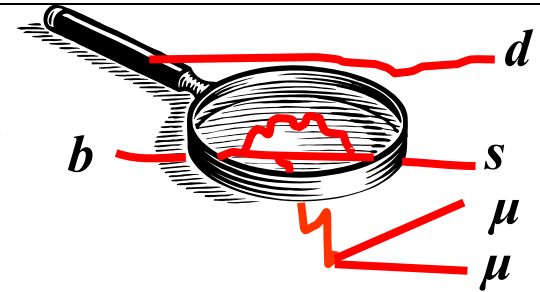
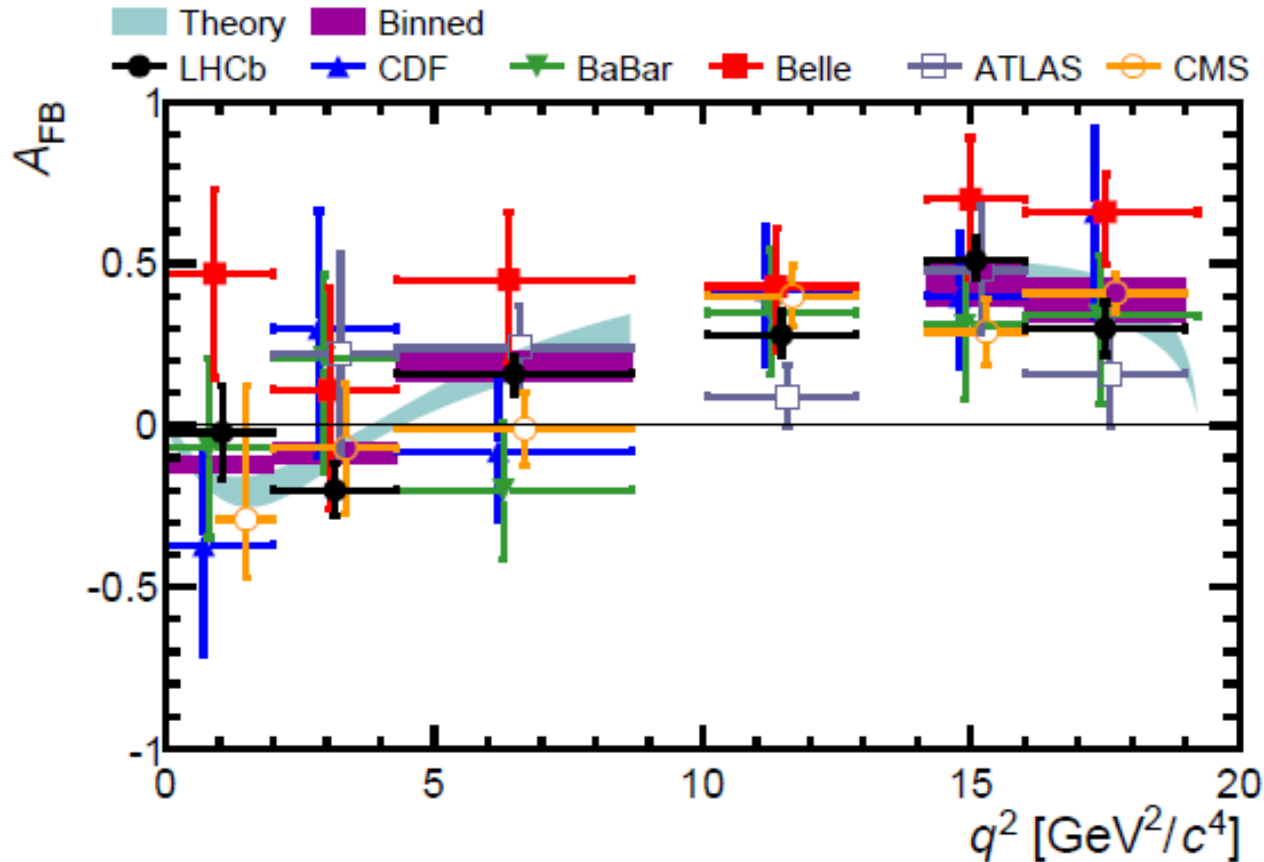


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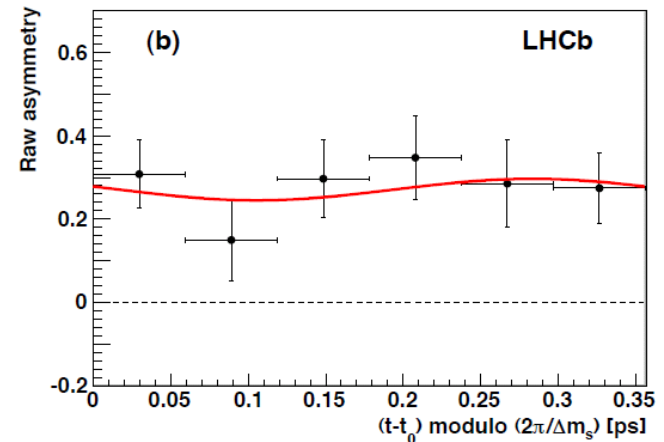
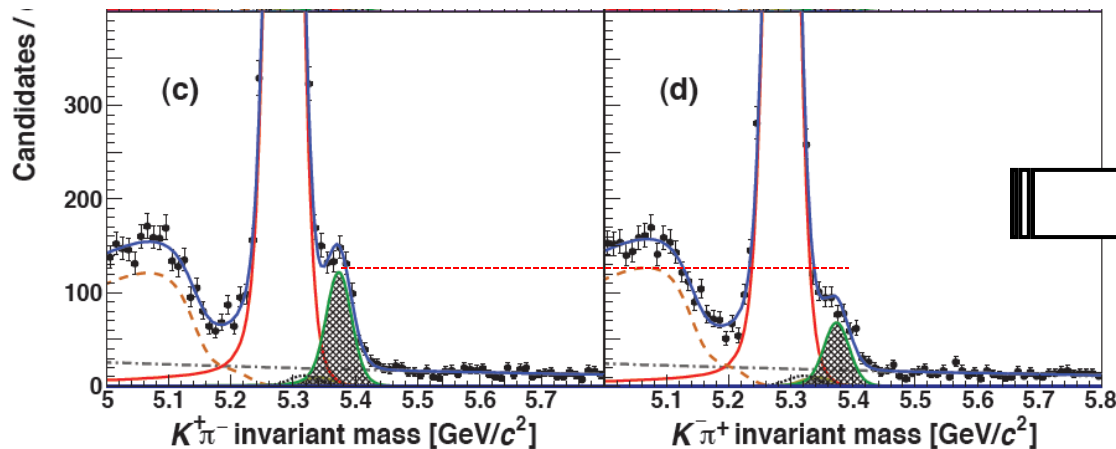
First observation of CP violation in B_s^0 system

3) First observation of CP violation in the decays of B_s mesons

arXiv:1304.6173

- More $B_s^0 \rightarrow K^+ \pi^-$ decays wrt. $B_s^0 \rightarrow K^- \pi^+$ decays, $>5 \sigma$:

$$A_{CP}(B_s^0 \rightarrow K^- \pi^+) = 0.27 \pm 0.04 (\text{stat}) \pm 0.01 (\text{syst})$$



- Comparison to $B^0 \rightarrow K^+ \pi^-$ allows stringent test of SM: (or of SU(3) symmetry)

$$\Delta = \frac{A_{CP}(B^0 \rightarrow K^+ \pi^-)}{A_{CP}(B_s^0 \rightarrow K^- \pi^+)} + \frac{\mathcal{B}(B_s^0 \rightarrow K^- \pi^+) \tau_d}{\mathcal{B}(B^0 \rightarrow K^+ \pi^-) \tau_s} = 0$$

$$\Delta = -0.02 \pm 0.05 \pm 0.04$$

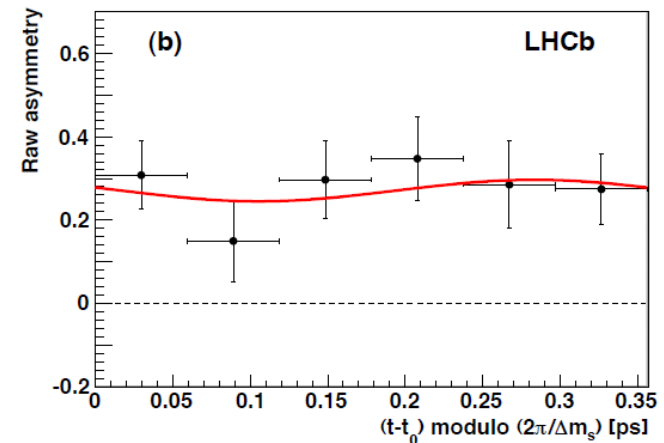
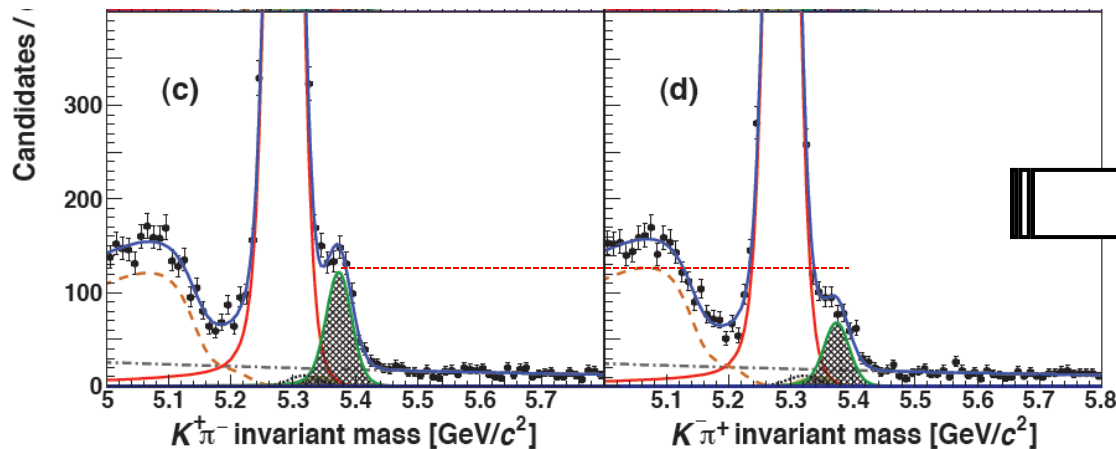
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History:

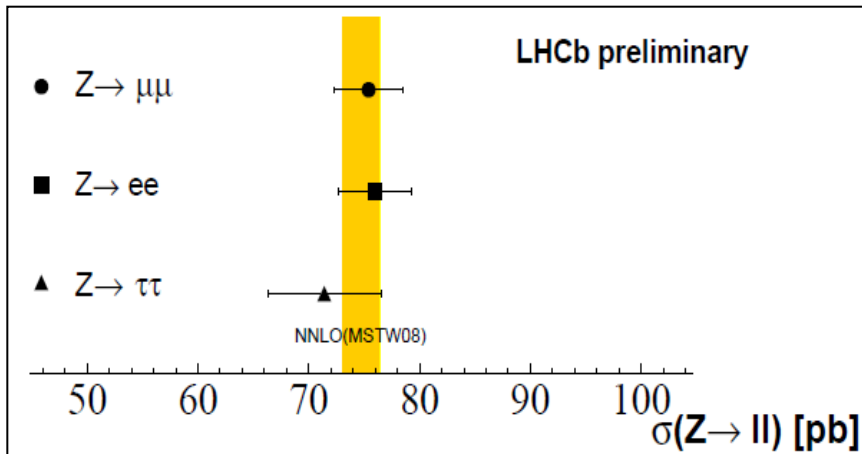
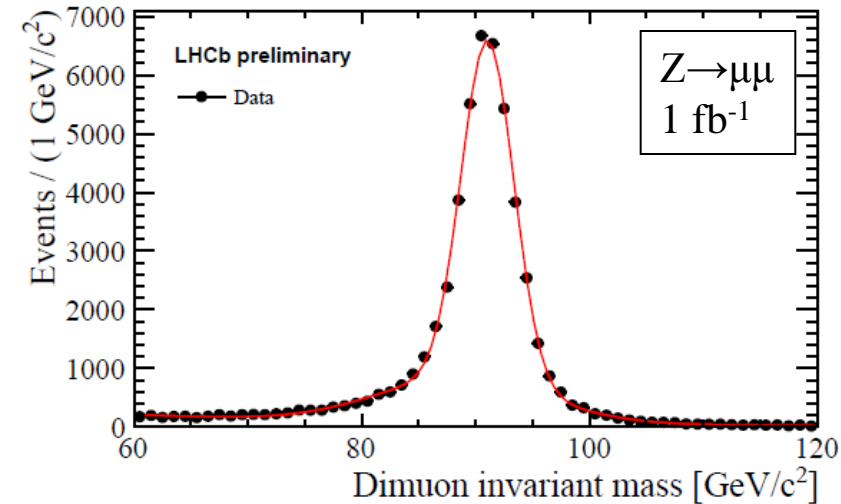
1964: Discovery of CPV with K_L^0 (Prize 1980)
2001: Discovery of CPV with B^0 (Prize 2008)



LHCb: “forward GPD”

- Measurement of the cross-section for $Z \rightarrow \mu\mu$ production with 1 fb^{-1} of pp collisions at $\sqrt{s}=7 \text{ TeV}$ [LHCb-CONF-2013-007](#)
- Graphical comparison of the LHCb measurements of W and Z boson production with ATLAS and CMS [LHCb-CONF-2013-005](#)

- Test the SM
- Constrain the pdf's
- Scrutinize lepton universality

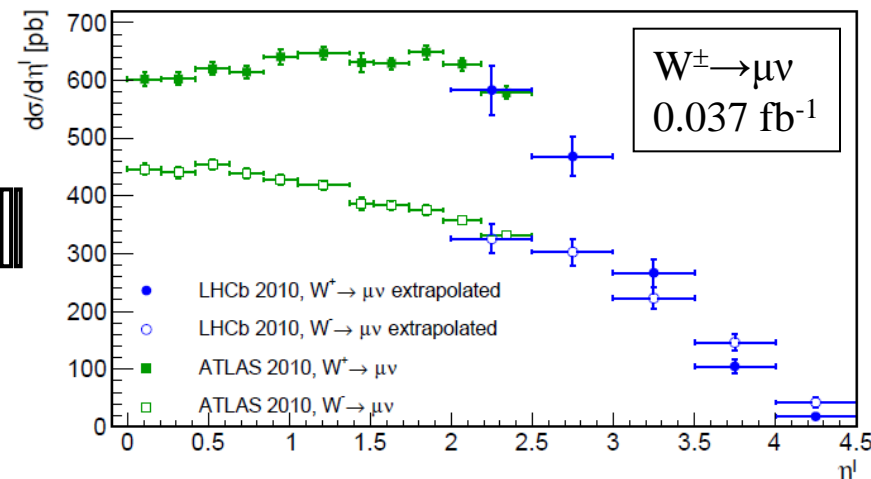
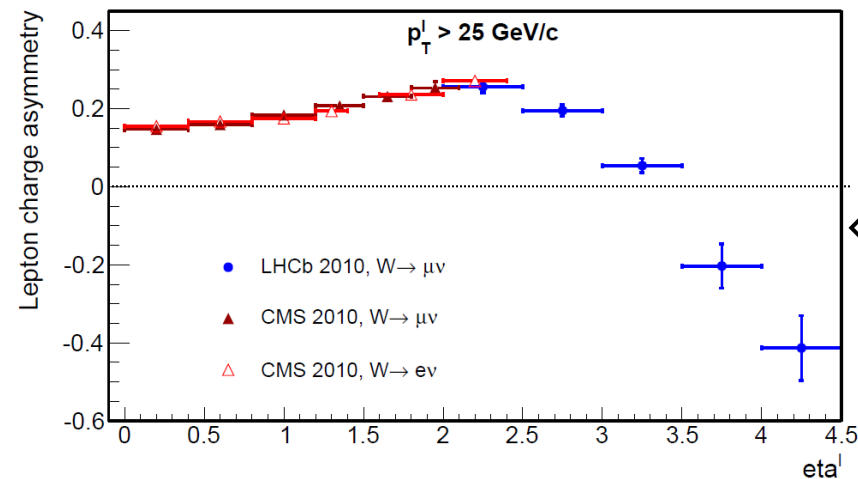
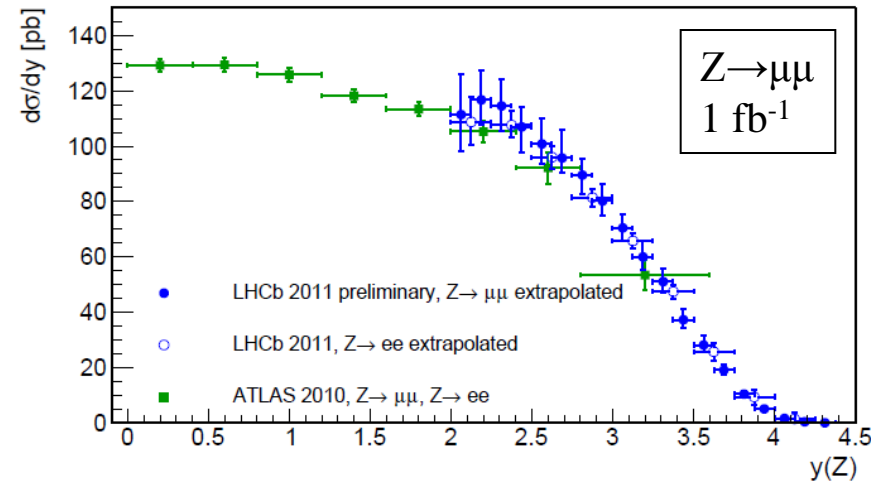


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➤ LHCb becomes "Forward GPD"

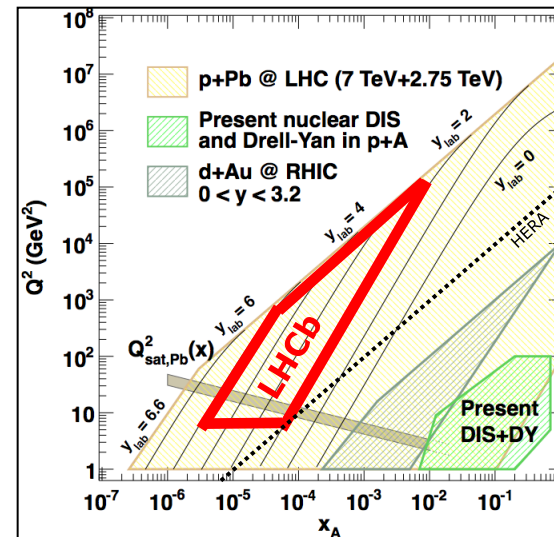
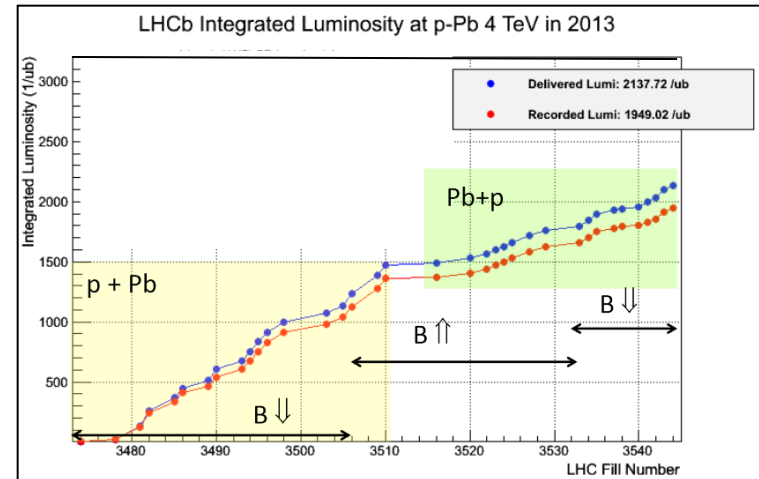


LHCb and heavy ions

Study of the J/ψ production cross-section in proton-lead collisions at $\sqrt{s_{NN}}=5$ TeV

LHCb-CONF-2013-008

- Collected 2 nb^{-1} of pA+Ap data
 - Results based on 0.75 nb^{-1} pA and 0.3 nb^{-1} Ap
- Unique acceptance coverage
 - pp: $2 < \eta < 5$
 - pA: $1.5 < \eta < 4.5$
 - Ap: $-5.5 < \eta < -2.5$

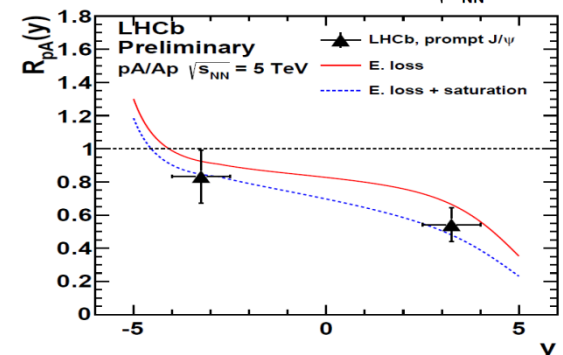
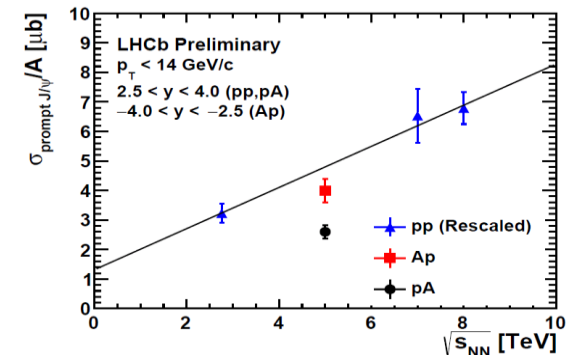
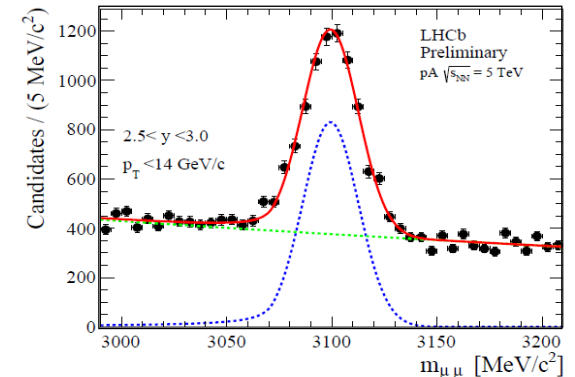


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LHCb-CONF-2013-008

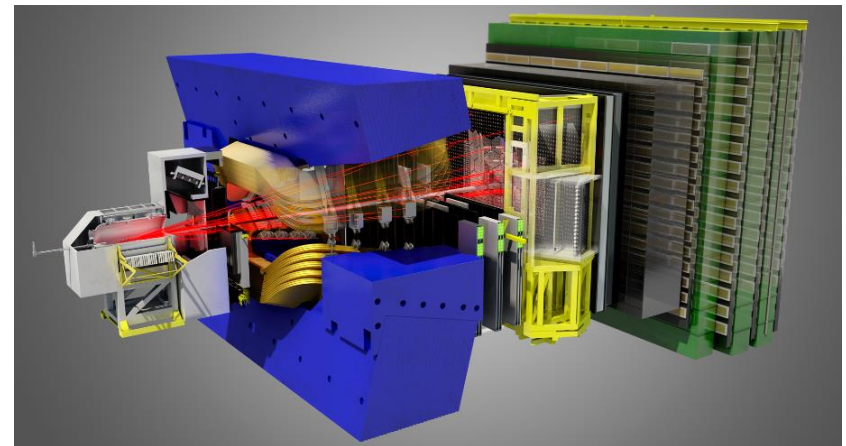
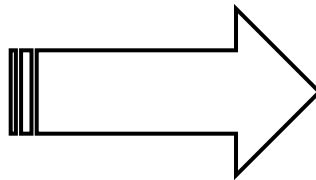
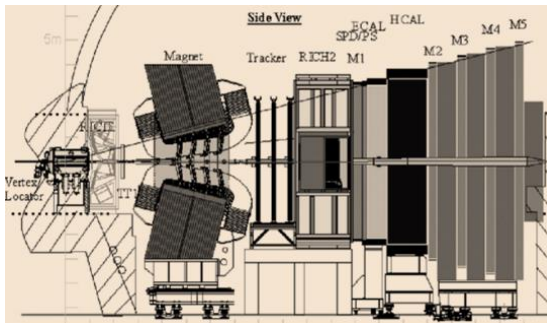
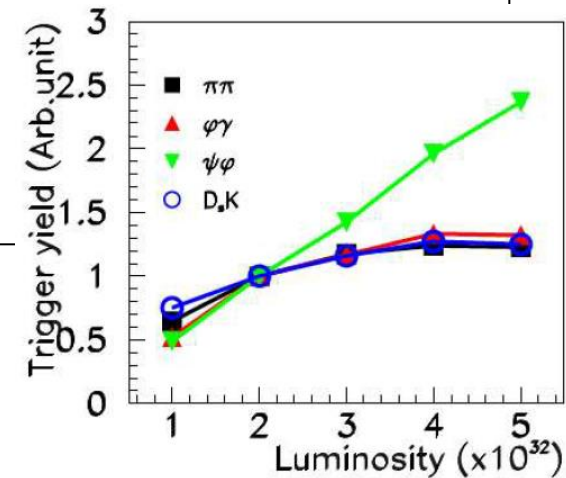
- Measured J/ψ production
 - 1) Prompt and from-b
 - 2) pA, Ap
 - 3) Nuclear suppression (wrt pp)
- Cross section vs \sqrt{s}
 - Scaled by $1/A$
 - In common rapidity range: $2.5 < |y| < 4$
- Nuclear attenuation
 - Agreement with theoretical predictions
 - Precision insufficient to prove saturation



LHCb upgrade

Need more luminosity (most analyses statistics limited!)

- Higher lumi \rightarrow higher rate \rightarrow higher E_T threshold \rightarrow loss of events
 - Better trigger needed: 40 MHz readout
- Higher lumi \rightarrow higher occupancy \rightarrow loss of tracks
 - Redesign of Tracker needed: technology choices

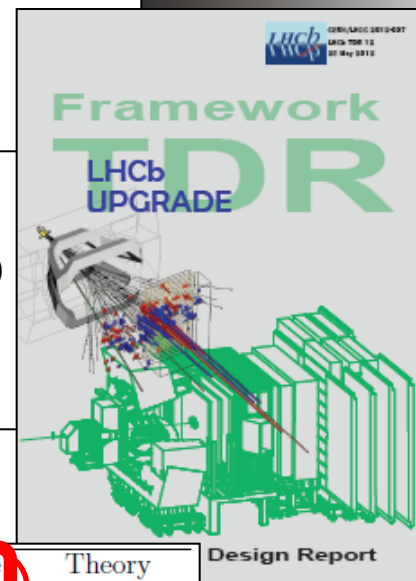


LHCb upgrade

Framework TDR

CERN-LHCC-2012-007

- Currently: 3 fb^{-1}
- 2015-2017: $4\text{--}5 \text{ fb}^{-1}$ (@25 ns, @ $\sqrt{s}=13 \text{ TeV}$)
- Upgrade (LS2, 18 months): 50 fb^{-1}

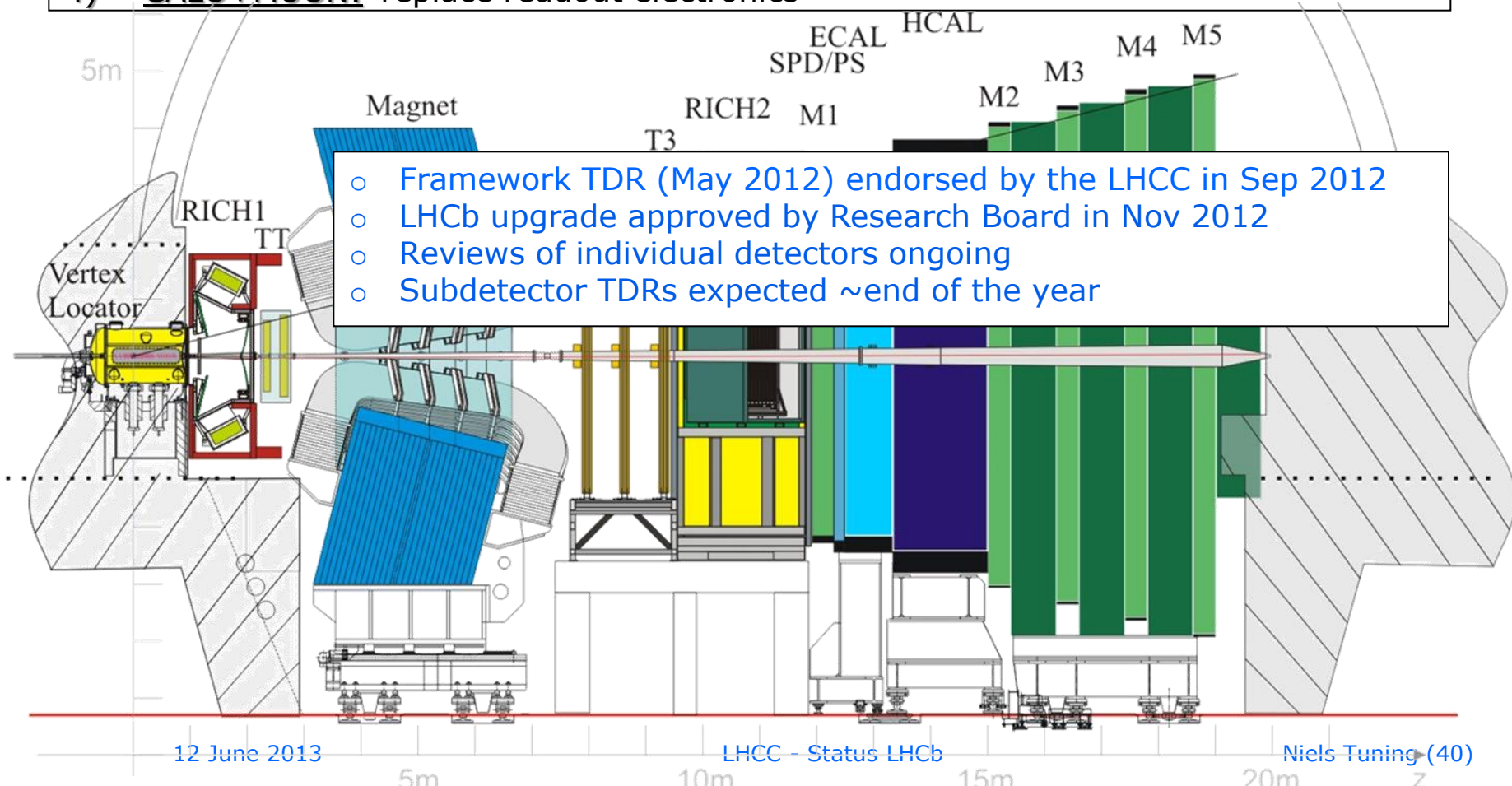


Type	Observable	Current precision	LHCb 2018	Upgrade (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s (B_s^0 \rightarrow J/\psi \phi)$	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s (B_s^0 \rightarrow J/\psi f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\text{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow \phi \phi)$	—	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow K^{*0} \bar{K}^{*0})$	—	0.13	0.02	< 0.02
	$2\beta_s^{\text{eff}}(B^0 \rightarrow \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow \phi \gamma)$	—	0.09	0.02	< 0.01
	$\tau^{\text{eff}}(B_s^0 \rightarrow \phi \gamma)/\tau_{B_s^0}$	—	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \rightarrow K^{*0} \mu^+ \mu^-; 1 < q^2 < 6 \text{ GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0 A_{\text{FB}}(B^0 \rightarrow K^{*0} \mu^+ \mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_1(K \mu^+ \mu^-; 1 < q^2 < 6 \text{ GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-)/\mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-)$	25 % [16]	8 %	2.5 %	$\sim 10 \%$
Higgs penguin	$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-)/\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$	—	$\sim 100 \%$	$\sim 35 \%$	$\sim 5 \%$
Unitarity triangle angles	$\gamma (B \rightarrow D^{(*)} K^{(*)})$	$\sim 10\text{--}12^\circ$ [19, 20]	4°	0.9°	negligible
	$\gamma (B_s^0 \rightarrow D_s K)$	—	11°	2.0°	negligible
	$\beta (B^0 \rightarrow J/\psi K_S^0)$	0.8° [18]	0.6°	0.2°	negligible
Charm	A_{F}	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	—
CP violation	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	—

LHCb upgrade (2018, need 18 months)

Trigger: 40 MHz readout (full software trigger)

- 1) VELO: decision strip or pixel option this month
- 2) RICH: decision on new opt. system or Trident this month
- 3) Tracker+ TT: decision on Scintillating Fibers at end of this year
- 4) CALO+MUON: replace readout electronics



LHCb upgrade (2018)

1) VELO:

Speed in trigger
Track finding ϵ vs ghosts
IP resolution
Radiation hardness

2) RICH:

(NB: HPD \rightarrow PMT)
Occupancies
Photon yield
Cherenkov angle resolution
Magnetic shielding

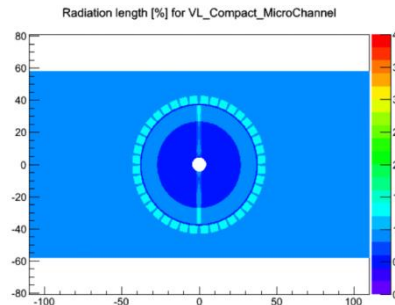
3) Tracker:

Track ϵ vs ghosts
Infrastructure
Logistics

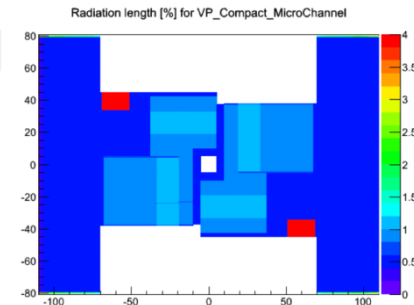
TT \rightarrow UT

Size of beam hole
Light support
Cooling

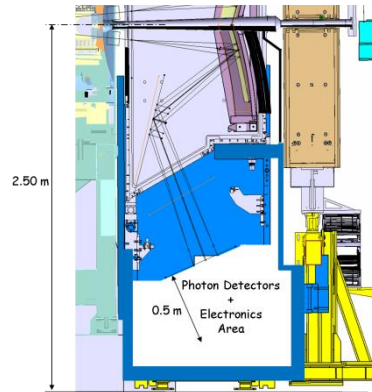
Strip



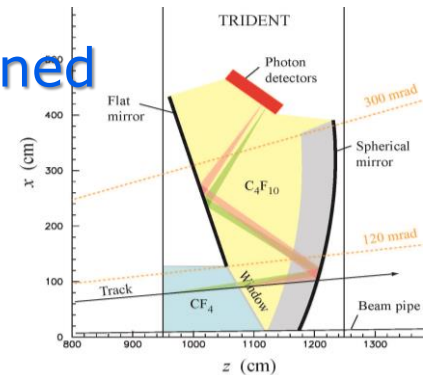
Pixel



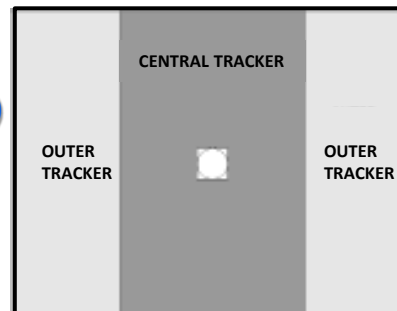
Modified
RICH1



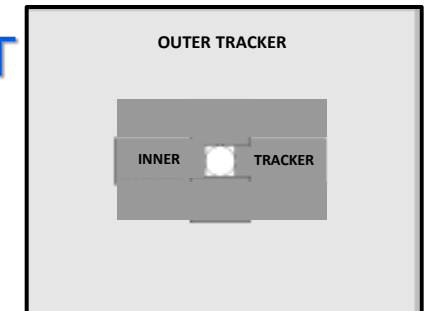
Combined
RICH



Sci.Fi+OT
(or full Sci.Fi.)



IT+OT



Conclusions

- Detectors are in good shape
- Wealth of physics results from 2010-2012 data
- Important technology choices for the upgrade in 2013

Thanks to the colleagues
from the injectors and the LHC !!

Looking forward to 2015
(25ns & 13 TeV)

Backup

CONF Notes in 2013

- | | | |
|----|--|---|
| 1) | Study of the J/ψ production cross-section in proton-lead collisions at $\sqrt{s_{NN}}=5$ TeV | <u>LHCb-CONF-2013-008</u> |
| 2) | Measurement of the cross-section for $Z \rightarrow \mu\mu$ production with 1 fb^{-1} of pp collisions at $\sqrt{s}=7$ TeV | <u>LHCb-CONF-2013-007</u> |
| 3) | Improved constraints on γ from $B^\pm \rightarrow DK^\pm$ decays including first results on 2012 data | <u>LHCb-CONF-2013-006</u> |
| 4) | Graphical comparison of the LHCb measurements of W and Z boson production with ATLAS and CMS | <u>LHCb-CONF-2013-005</u> |
| 5) | Model-independent measurement of CP violation parameters in $B^\pm \rightarrow (K^0_S h^+ h^-)_D K^\pm$ decays | <u>LHCb-CONF-2013-004</u> |
| 6) | A search for time-integrated CP violation in $D^0 \rightarrow K^- K^+$ and $D^0 \rightarrow \pi^- \pi^+$ decays | <u>LHCb-CONF-2013-003</u> |
| 7) | Measurement of $\sigma(bb^-)$ with inclusive final states | <u>LHCb-CONF-2013-002</u> |
| 8) | Measurement of the forward-central bb^- production asymmetry | <u>LHCb-CONF-2013-001</u> |

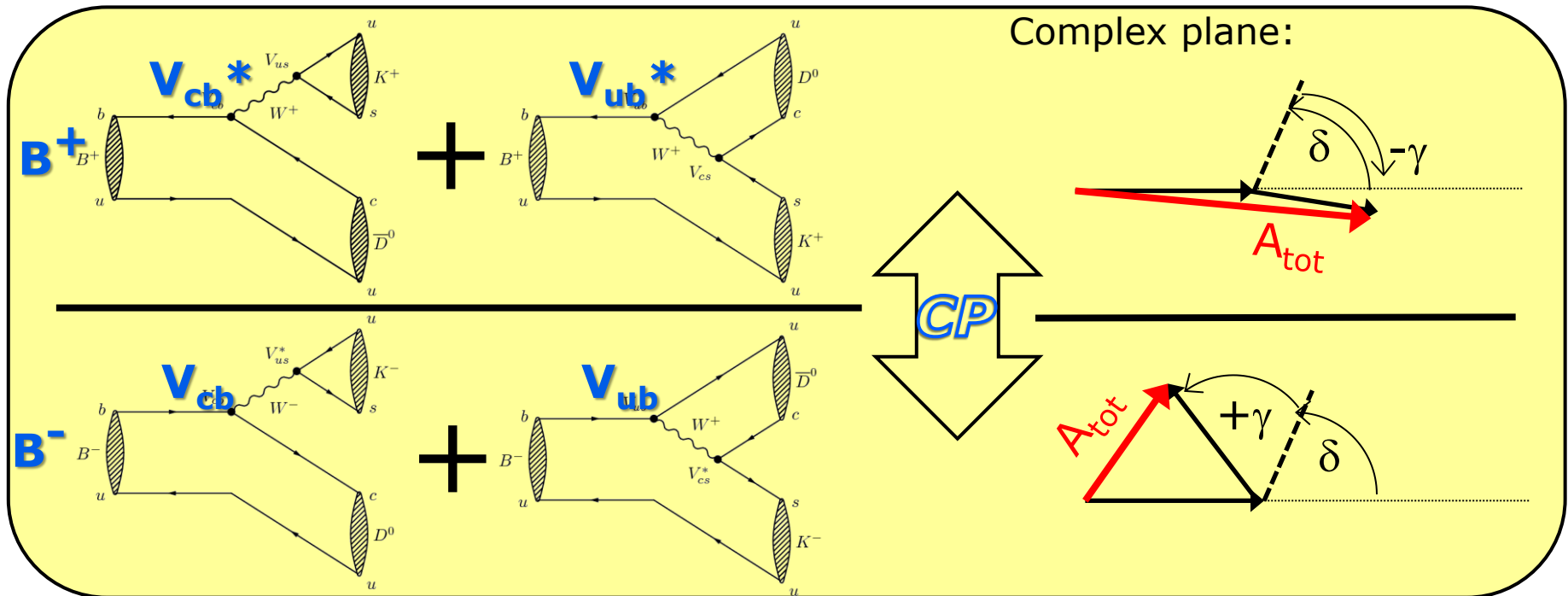
Determination of γ

1) Measurement of the CKM angle γ from a combination of $B \rightarrow Dh$ analyses

arXiv:1305.2050

- Relative weak phase of two amplitudes in $B^\pm \rightarrow DK^\pm$ decays: γ

What can happen when *two* amplitudes contribute to a decay:



Angular observables

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

$$\frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_K d\phi} = \frac{9}{32\pi} \left[S_1^s \sin^2 \theta_K + S_1^c \cos^2 \theta_K + \right. \\ S_2^s \sin^2 \theta_K \cos 2\theta_\ell + S_2^c \cos^2 \theta_K \cos 2\theta_\ell + \\ S_3 \sin^2 \theta_K \sin^2 \theta_\ell \cos 2\phi + S_4 \sin 2\theta_K \sin 2\theta_\ell \cos \phi + \\ S_5 \sin 2\theta_K \sin \theta_\ell \cos \phi + S_6 \sin^2 \theta_K \cos \theta_\ell + \\ S_7 \sin 2\theta_K \sin \theta_\ell \sin \phi + S_8 \sin 2\theta_K \sin 2\theta_\ell \sin \phi + \\ \left. S_9 \sin^2 \theta_K \sin^2 \theta_\ell \sin 2\phi \right] ,$$

$$\frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_K d\hat{\phi}} = \frac{9}{16\pi} \left[F_L \cos^2 \theta_K + \frac{3}{4}(1 - F_L)(1 - \cos^2 \theta_K) - \right. \\ F_L \cos^2 \theta_K (2 \cos^2 \theta_\ell - 1) + \\ \frac{1}{4}(1 - F_L)(1 - \cos^2 \theta_K)(2 \cos^2 \theta_\ell - 1) + \\ S_3(1 - \cos^2 \theta_K)(1 - \cos^2 \theta_\ell) \cos 2\hat{\phi} + \\ \frac{4}{3}A_{\text{FB}}(1 - \cos^2 \theta_K) \cos \theta_\ell + \\ \left. A_9(1 - \cos^2 \theta_K)(1 - \cos^2 \theta_\ell) \sin 2\hat{\phi} \right]$$

$$\hat{\phi} = \begin{cases} \phi + \pi & \text{if } \phi < 0 \\ \phi & \text{otherwise} \end{cases}$$