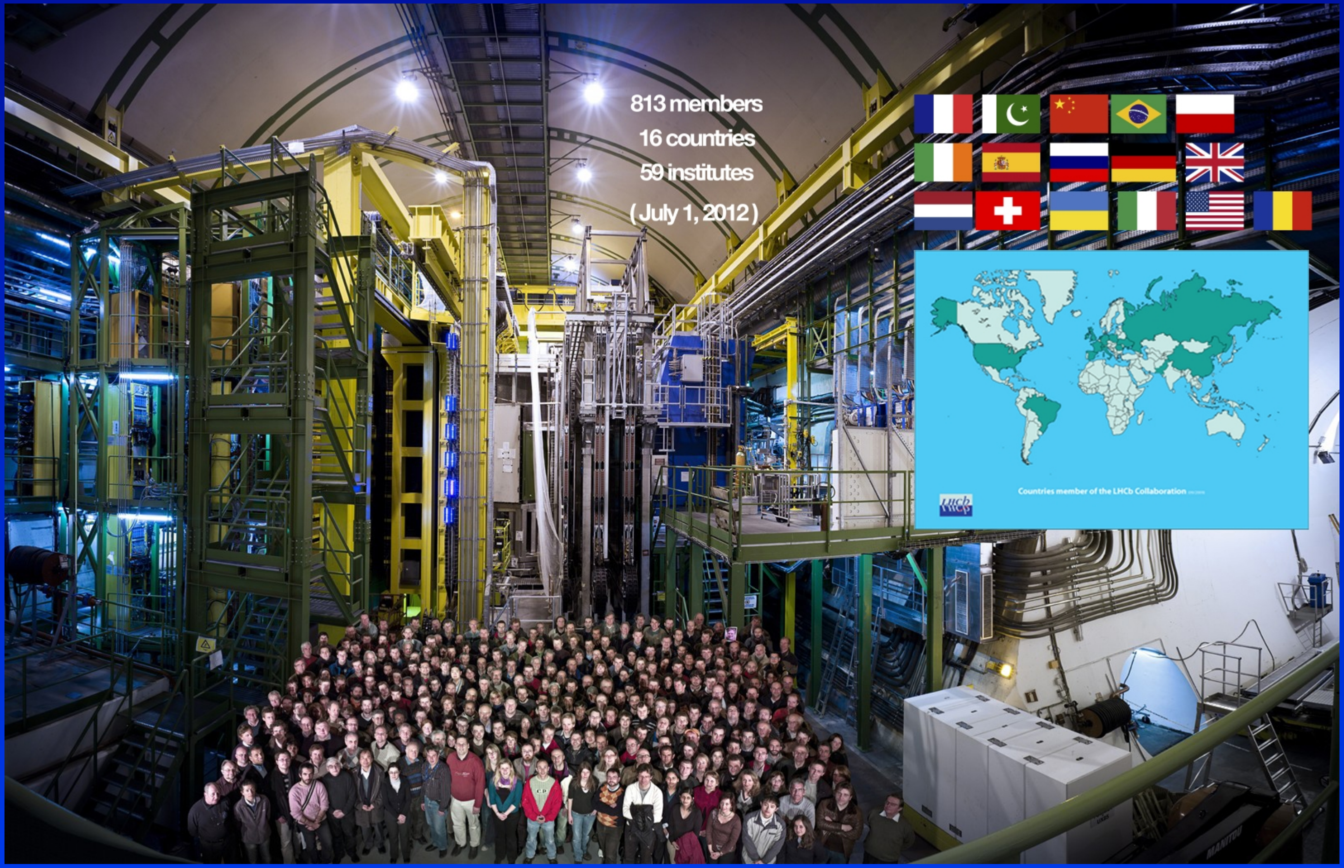
FLASY 2013

July 2nd, 2013

LHCb Overview



Jörg Marks, Heidelberg University
on behalf of the LHCb collaboration

LHC – b and c Quark Production

The LHC is also a heavy flavour factory

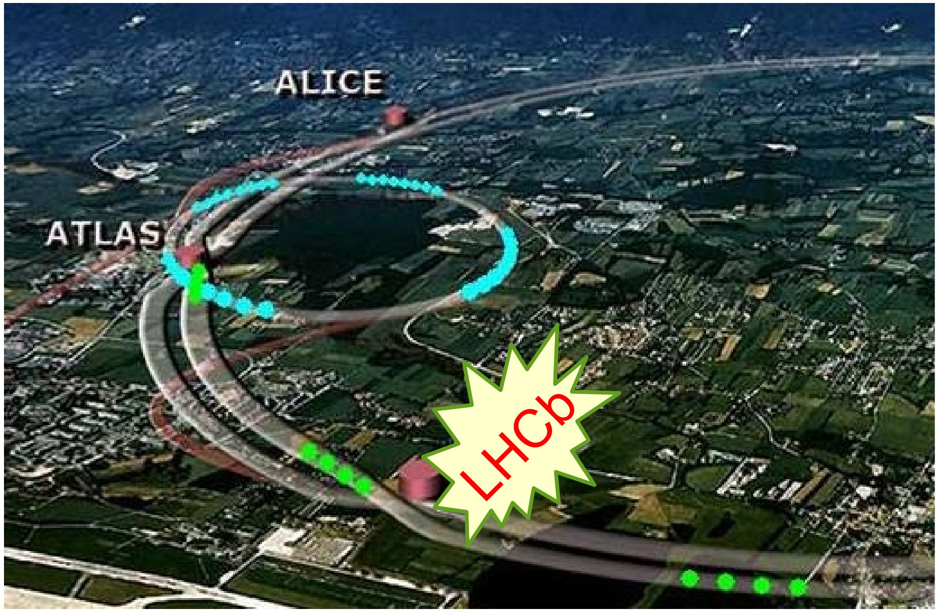
$$\sigma(\sqrt{s} = 7\,TeV\,,\, pp \rightarrow c\bar{c}X) \approx 6\ mb$$

Phys. Lett. B 694, 209 (2010)

$$\sigma(\sqrt{s} = 7\,TeV\,,\, pp \rightarrow b\bar{b}X) \approx 0.3\ mb$$

Nucl. Phys. B 871, (2013)

LHC – b and c Quark Production



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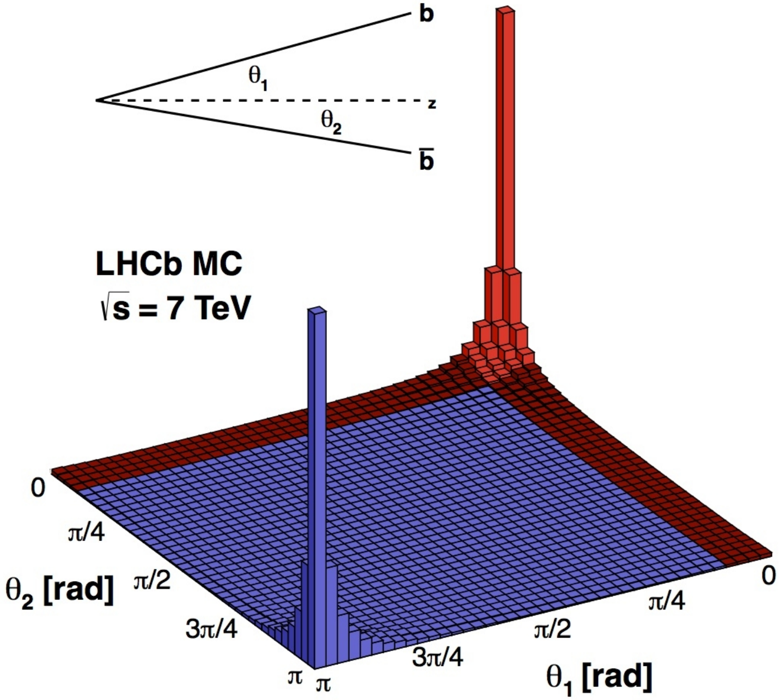
Phys. Lett. B 694, 209 (2010)

$$\sigma(\sqrt{s} = 7\,TeV\,,\, pp \rightarrow b\bar{b}X) \approx 0.3\ mb$$

Nucl. Phys. B 871, (2013)

- $b\bar{b}\,/\,c\bar{c}$ pairs are mainly produced in forward / backward direction

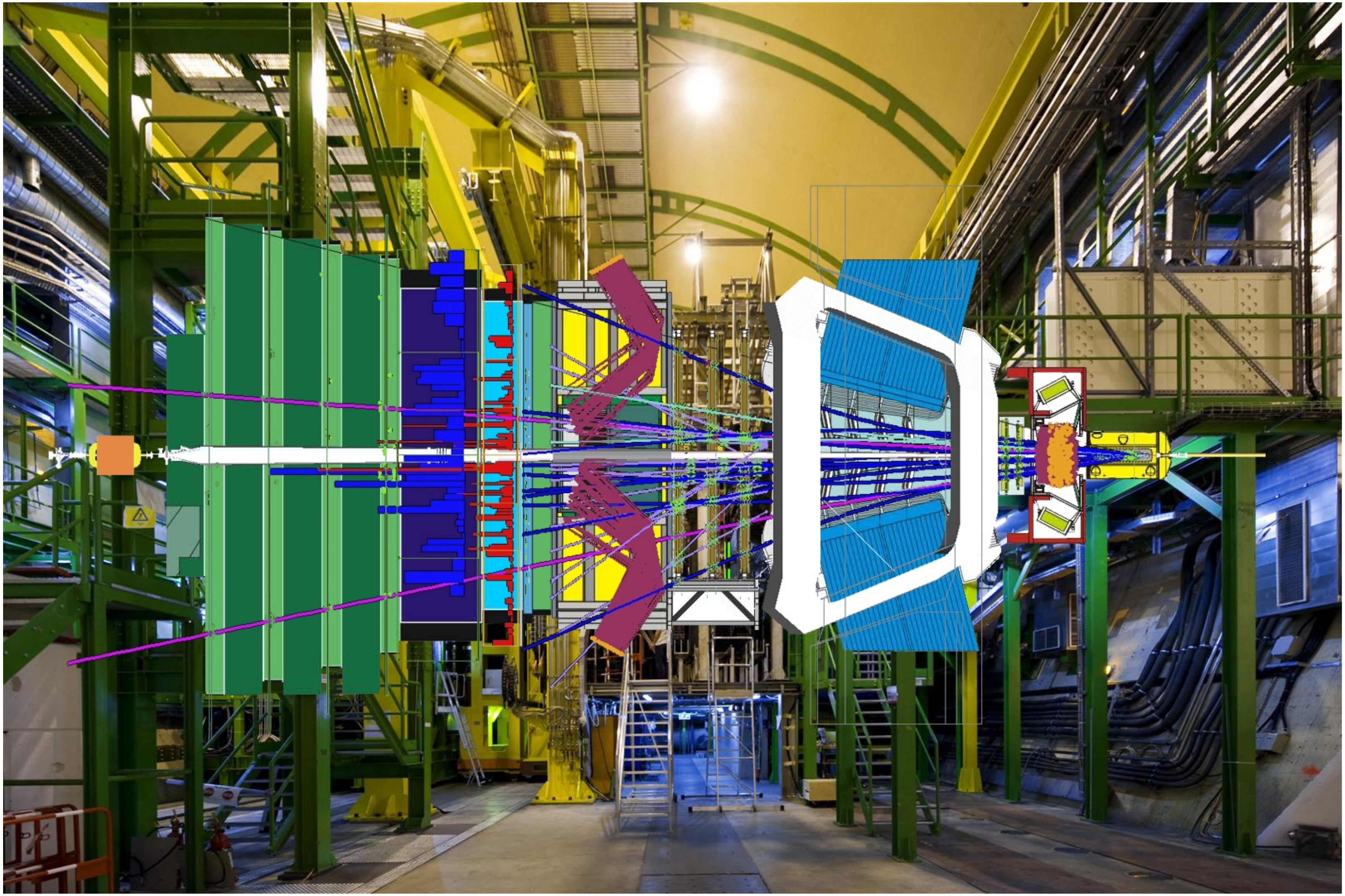


LHCb → forward spectrometer

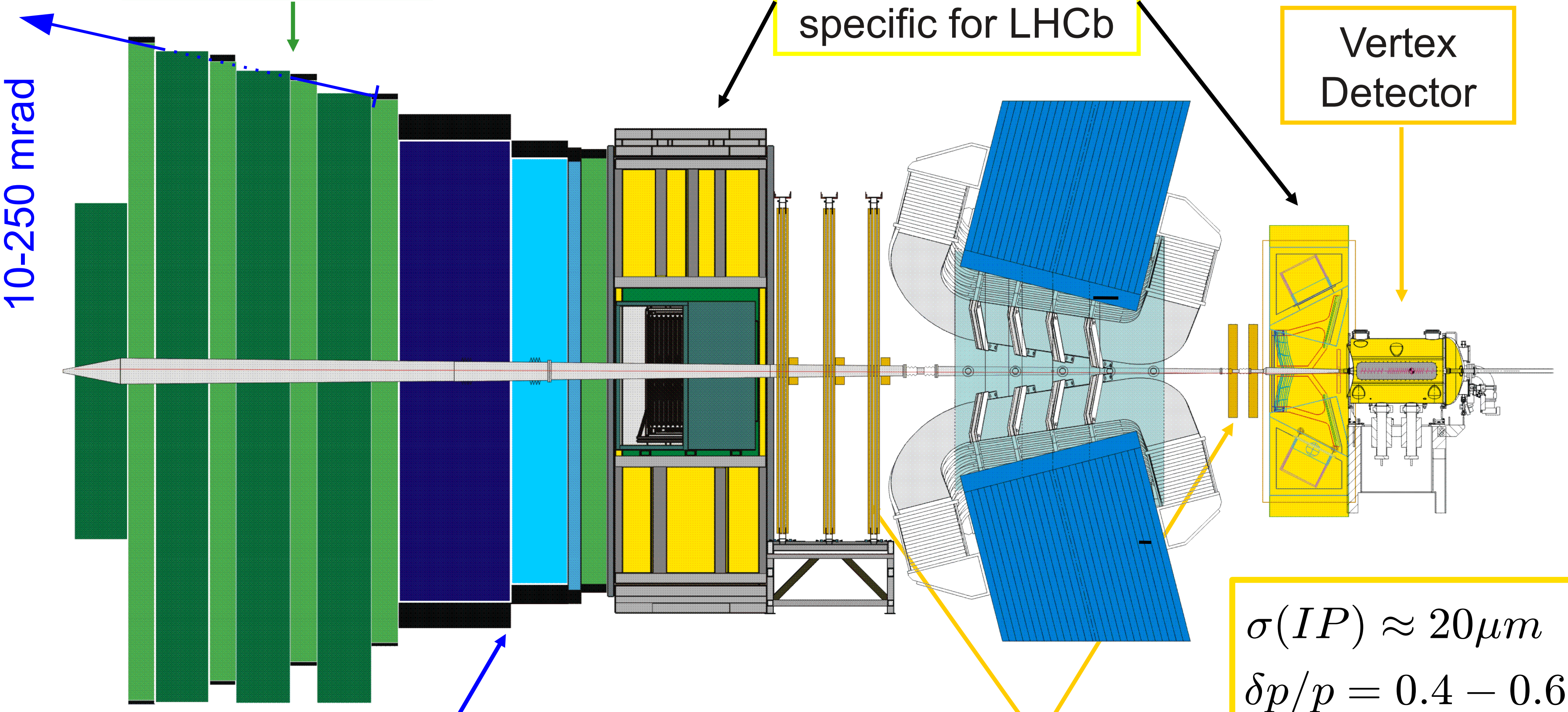
LHCb Detector

LHCb Detector

10-250 mrad



LHCb Experimental Setup



Muon System

RICH Detectors specific for LHCb

JINST 3, (2008) S08005

Vertex Detector

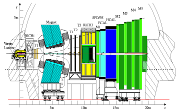
Calorimeters

Tracking System

$\sigma(IP) \approx 20\mu m$

$\delta p/p = 0.4 - 0.6\ \%$

$\epsilon_{track} > 96\ \%$



LHCb Experimental Setup

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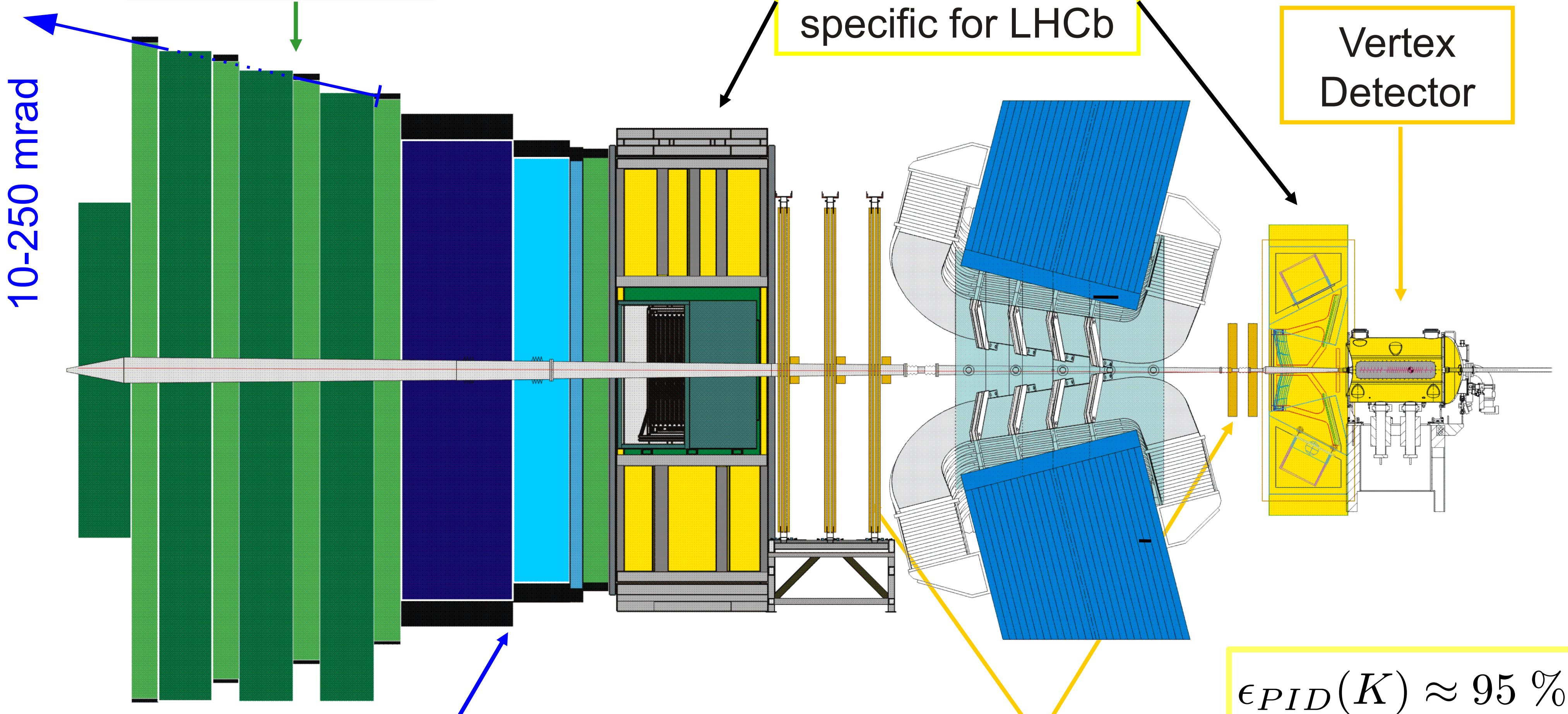

Muon System

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10-250 mrad

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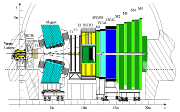
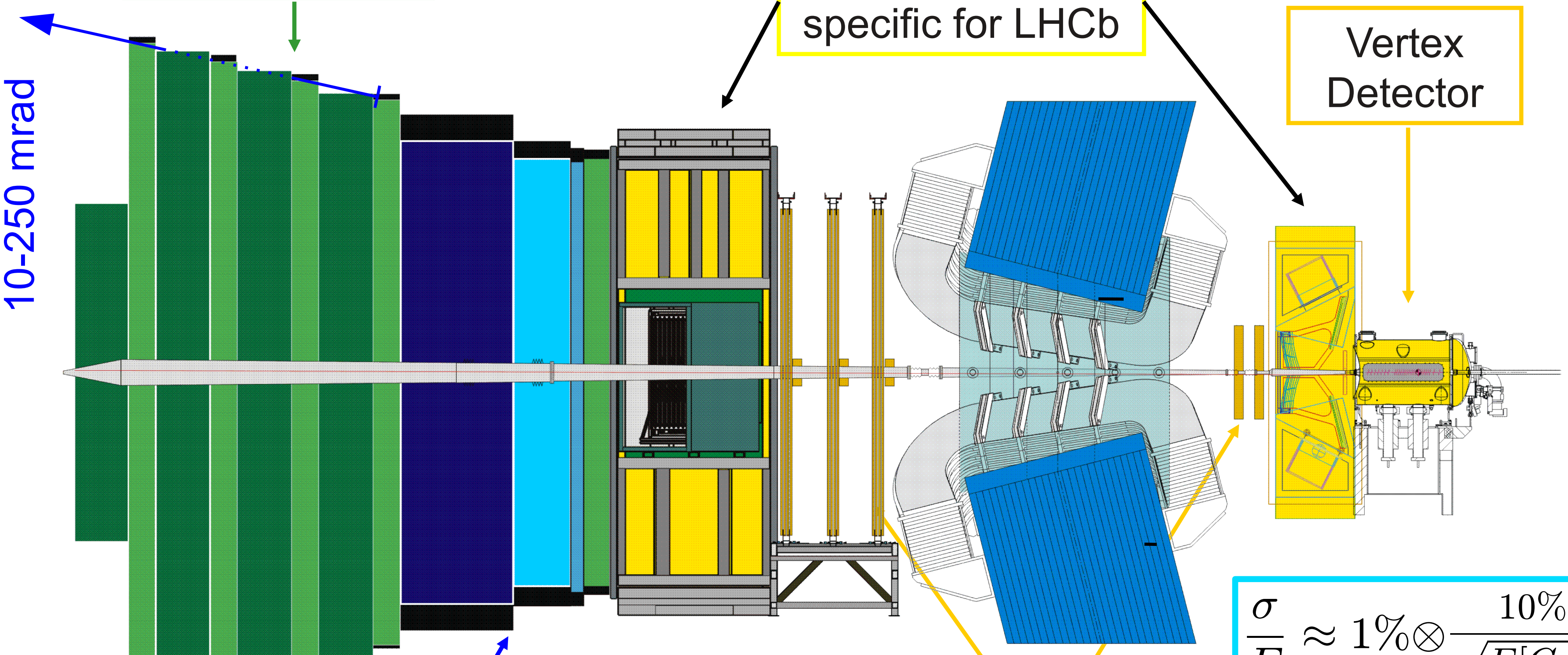
Tracking System

$\epsilon_{PID}(K) \approx 95\ \%$

MisID $(K \rightarrow \pi) \approx 5\ \%$



LHCb Experimental Setup



Muon System

RICH Detectors specific for LHCb

JINST 3, (2008) S08005

Vertex Detector

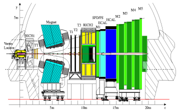
Calorimeters

Tracking System

$$\frac{\sigma}{E} \approx 1\% \otimes \frac{10\%}{\sqrt{E[GeV]}}$$

$$\epsilon_{PID}(e) \approx 95\ \%$$

$$\mathit{MisID}\ (e \rightarrow h)\ \approx 5\ \%$$



LHCb Experimental Setup

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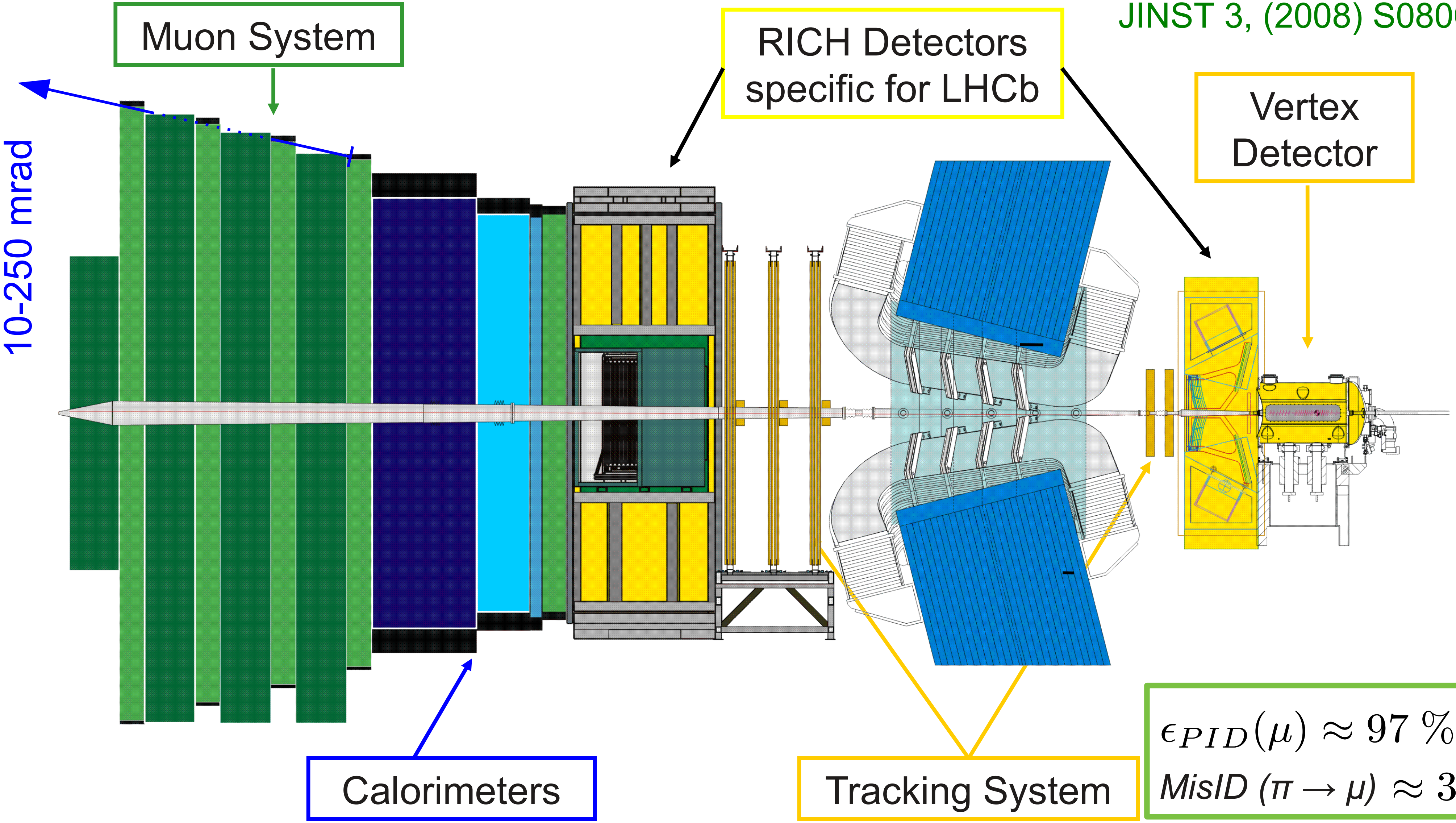
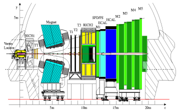


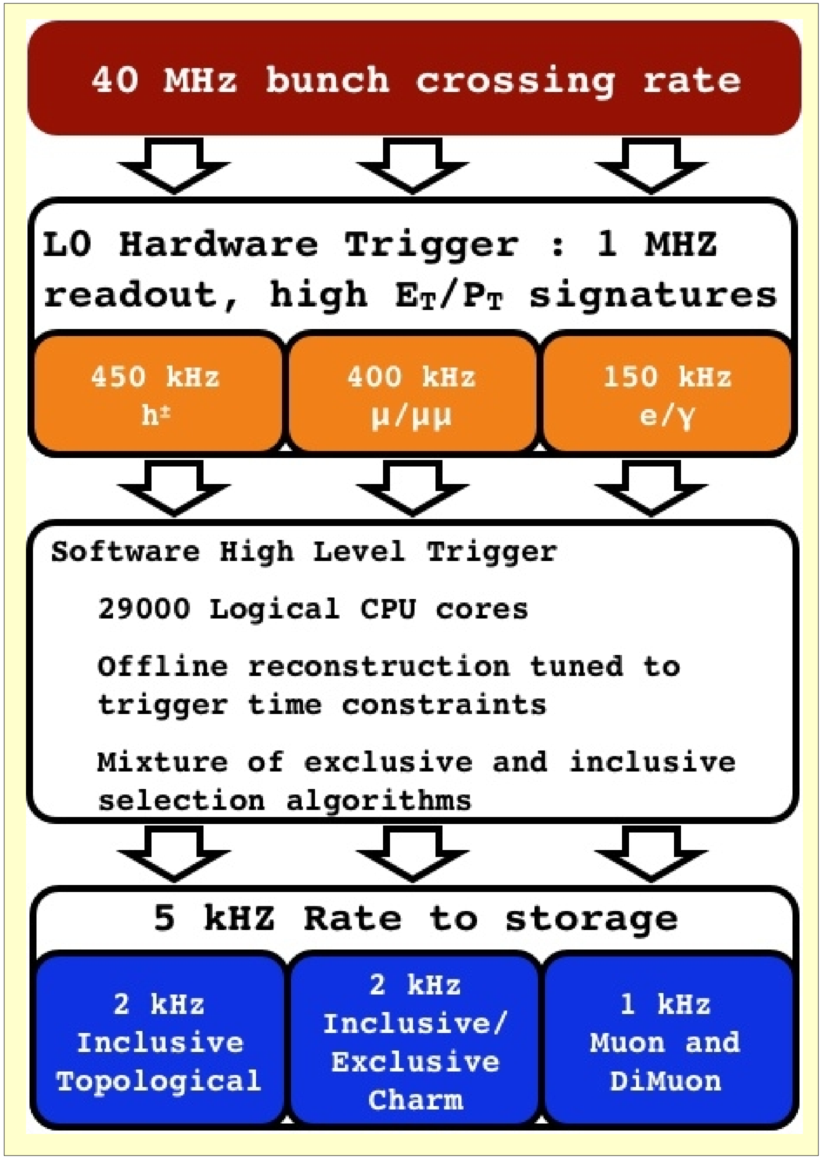
$\epsilon_{PID}(\mu) \approx 97\ \%$

MisID $(\pi \rightarrow \mu) \approx 3\ \%$



LHCb - Trigger Overview

- Hardware Trigger based on VELO, Calorimeter- and Muonsystem
  - Select on p_T objects: $h, \mu, \mu\mu, e^{\pm}, \gamma, \pi^0$
  - Obtain p-p interaction and multiplicity info
- Two level software trigger based on partly / fully reconstructed objects with all detector information
  - Confirm L0 trigger using reconstr. and combined detector info
  - Select on a single track with high p_T and displaced vertices using VELO
  - Use reconstructed objects for exclusive and inclusive selections with clear signature
- In 2012 wrote 5 kHz to storage thanks to storing up to 25 % of data locally



40 MHz bunch crossing rate

L0 Hardware Trigger : 1 MHZ readout, high E_T/P_T signatures

450 kHz $h^{\pm}$	400 kHz $\mu/\mu\mu$	150 kHz e/γ

Software High Level Trigger

29000 Logical CPU cores

Offline reconstruction tuned to trigger time constraints

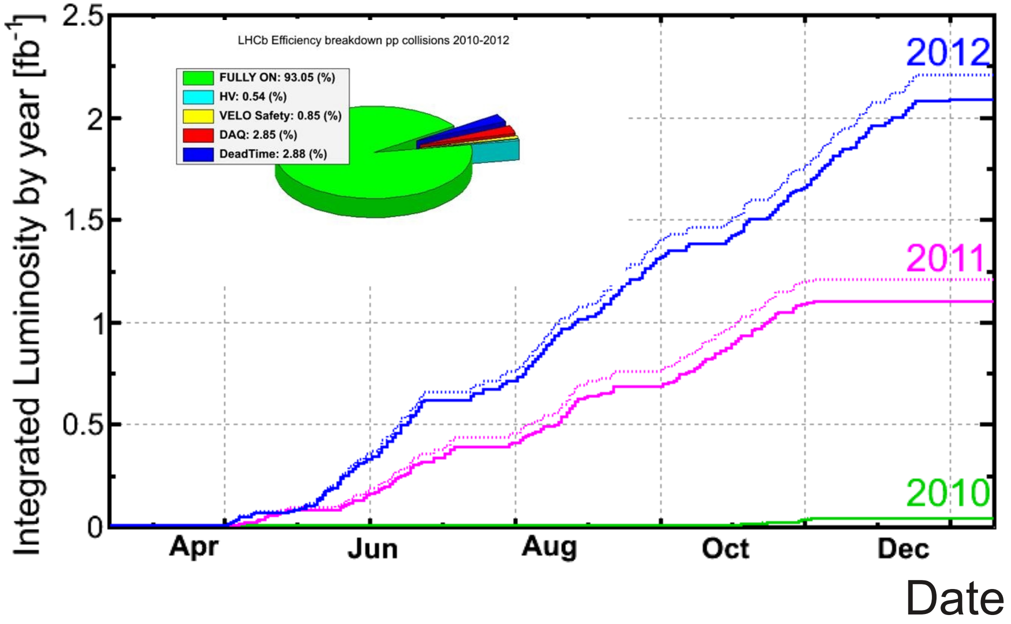
Mixture of exclusive and inclusive selection algorithms

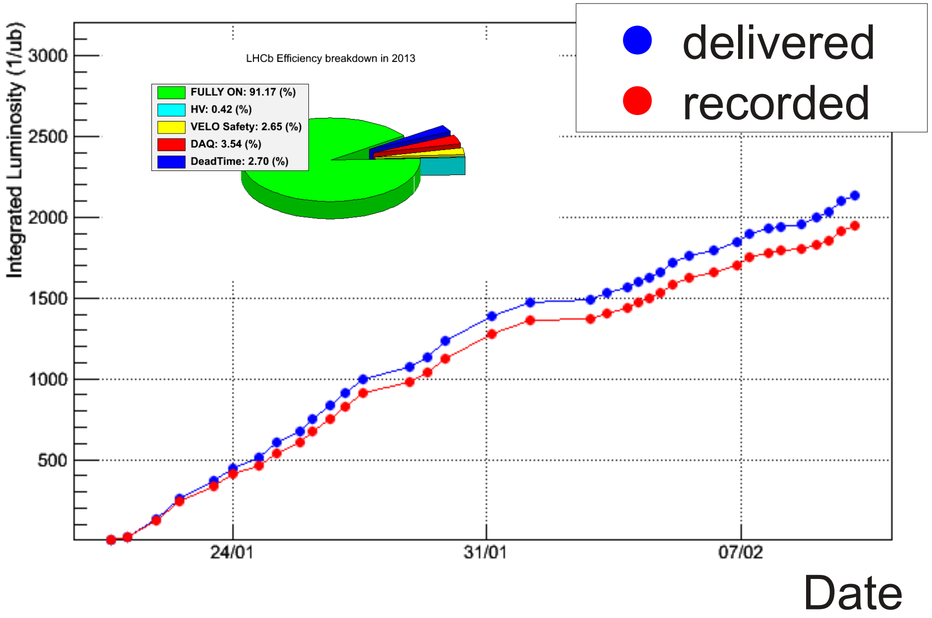
5 kHZ Rate to storage

2 kHz Inclusive Topological	2 kHz Inclusive/ Exclusive Charm	1 kHz Muon and DiMuon

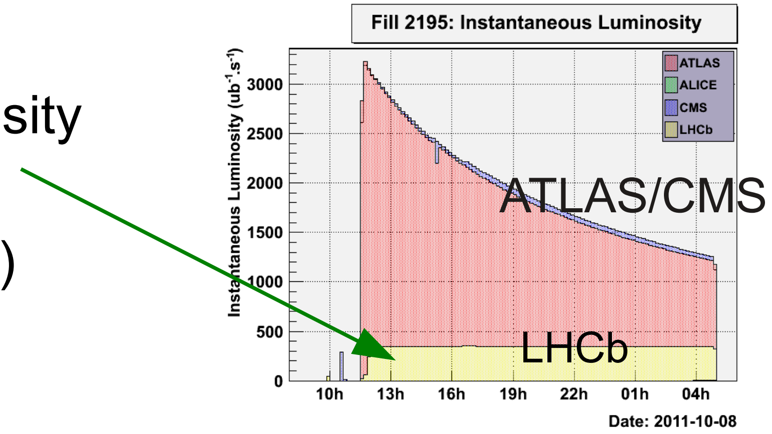
Operations in 2011 / 2012

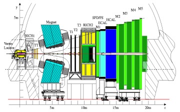
- p-p at 3.5 / 4 TeV
- p-Pb at $\sqrt{s_{NN}} = 5$ TeV in 2013





- LHCb operates with high efficiency
- Take data at constant instantaneous luminosity rate: $\mathcal{L} \approx 4 \times 10^{32}\, cm^{-2} s^{-1}$ (factor 2 larger than design luminosity)
- Visible pp interactions per bunch crossing μ = 1.7 (50 ns bunch spacing)





LHCb Physics Program

- Search for evidence of physics beyond the Standard Model in CP violation and rare decays of charm and beauty hadrons
  - Indirect search, probe large mass scales via the study of virtual quantum loops of new particles
- Only a few recent LHCb physics results can be covered here
  - Spectroscopy and production of heavy quarks
    Quantum numbers of X(3872), J/ψ / Υ production, and D mass measurement
  - Mixing and CP violation in the $B \ (B^+, B^0, B_s^0)$ system
    Δm_s , $\Delta\Gamma_s$, ϕ_s and CPV measurements, γ measurement arXiv:1305.2050, LHCb-CONF-2013-006
  - Mixing and CP violation in the D system (mixing in WS $D^0 \to K\pi$ and ΔA_{CP})
  - Rare decays $(B^0 \to K^*\mu\mu, B_s^0 \to \phi\mu\mu)$ $B^0_{(s)} \to \mu\mu$ arXiv:1211.2674
  - Soft QCD physics, pA and Ap results LHCb-CONF-2012-034, LHCb-CONF-2013-008
  - Electroweak physics

LHCb results are available in more than 125 papers submitted to journals and 110 conference contributions. https://cds.cern.ch/collection/LHCb%20Papers?ln=en
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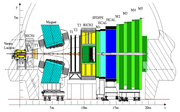

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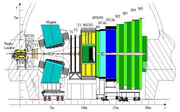
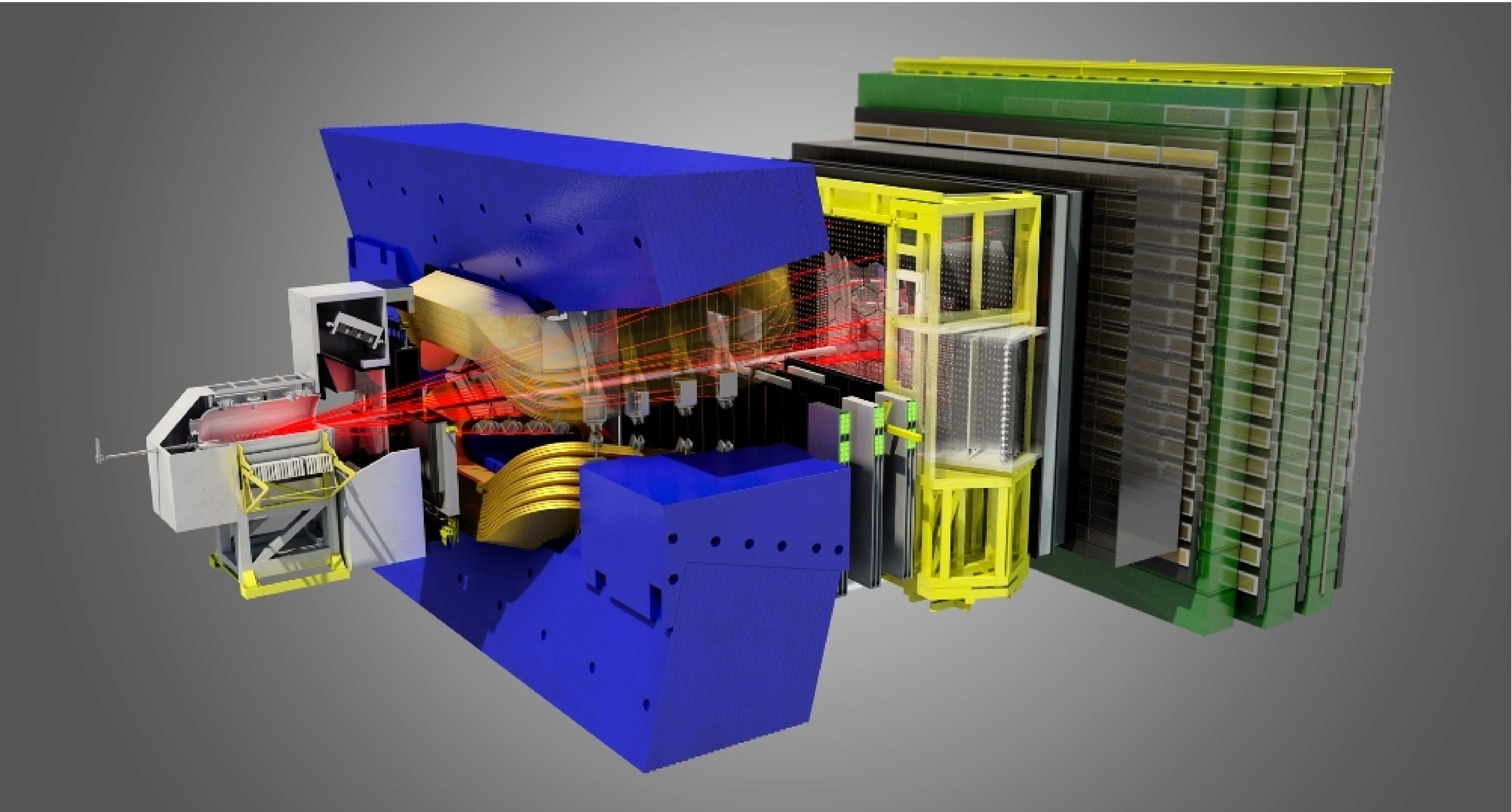


Selected results

Production and Spectroscopy

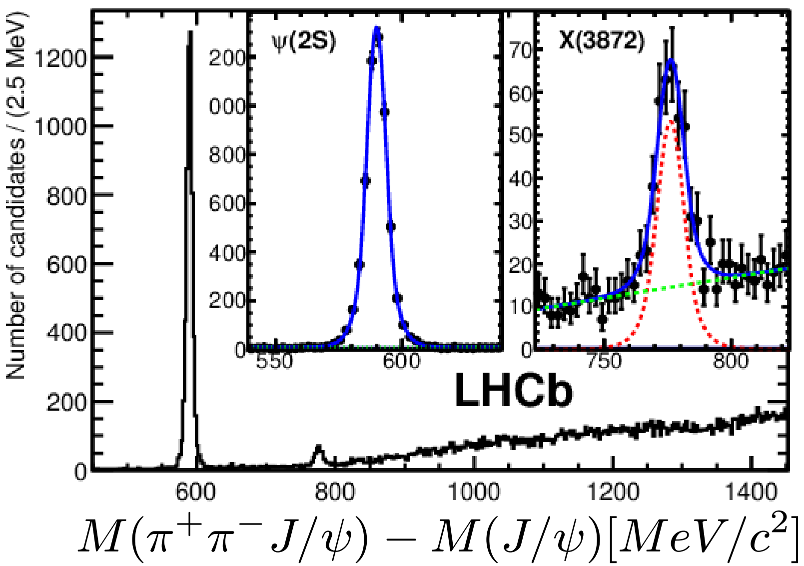


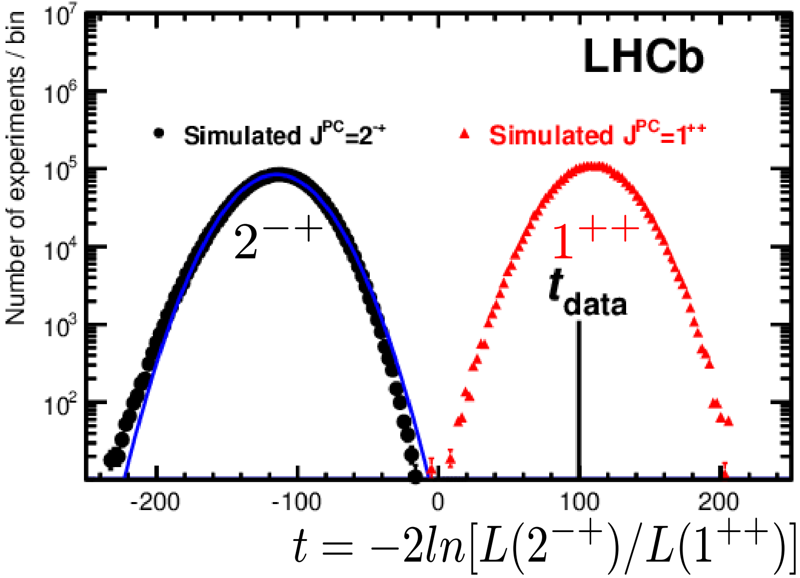
Quantum Numbers of X(3872)

10 years after the discovery of X(3872) two possible spin states remain $J^{PC} = 1^{++}$ or $J^{PC} = 2^{-+}$

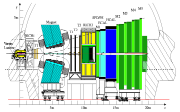
- Determine J^{PC} in a 5 d angular correlation analysis of $B^+ \rightarrow X(3872)K^+$, $X(3872) \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow \mu^+\mu^-$

arXiv: 1302.6269$(\int \mathcal{L} = 1 fb^{-1})$





- $J^{PC}(X(3872)) = 1^{++}$, exclude 2^{-+} with $> 8\sigma$
- The state $\eta_{c2}(1^1D_2)$ is excluded, favour unconventional interpretations $\chi_{c1}(2^3P_1)$, $D^{*0}\bar{D}^0$ molecule, tetra quarks or charmonium-molecules



D Meson Mass Measurements

Interpreting X(3872) as $D^{*0}D^0$ molecule E_B is determined by D mass measurements: $E_B = 0.16 \pm 0.26\, MeV/c^2$

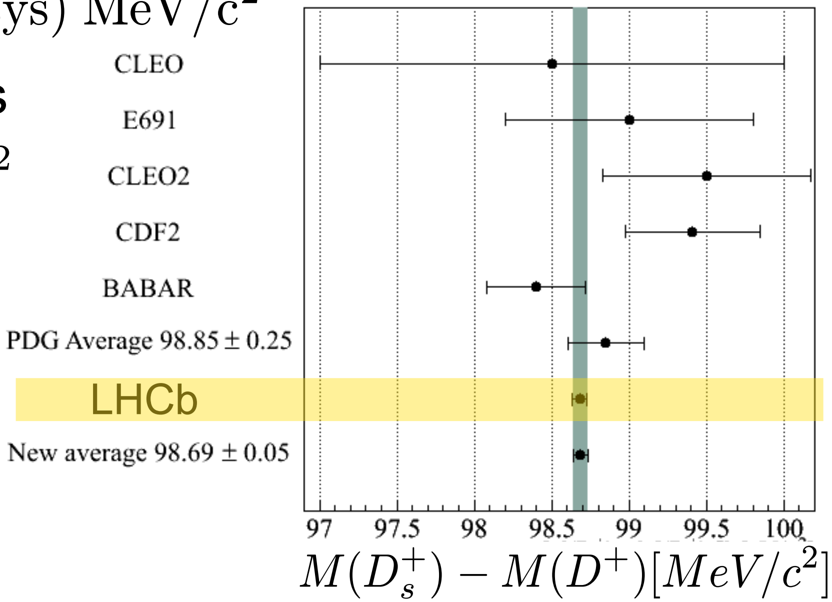
- Mass measurements in the D system arXiv: 1304.6865 $(\int \mathcal{L} = 1 fb^{-1})$
  - Determine D^0 mass in $D^0 \to K^+K^-K^-\pi^+$
    $M(D^0) = 1864.75 \pm 0.15(\mathrm{stat}) \pm 0.11(\mathrm{sys})\ \mathrm{MeV/c^2}$
  - Mass difference measurements
    $M(D^+) - M(D^0) = 4.76 \pm 0.12(\mathrm{stat}) \pm 0.07(\mathrm{sys})\ \mathrm{MeV/c^2}$
    $M(D_s^+) - M(D^+) = 98.68 \pm 0.03(\mathrm{stat}) \pm 0.04(\mathrm{sys})\ \mathrm{MeV/c^2}$

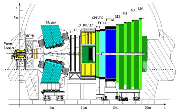
    Derive a significantly more precise D_s^+ mass
    $M(D_s^+) = 19684.19 \pm 0.20 \pm 0.14 \pm 0.08\ MeV/c^2$

  - Dominant syst. uncertainty on the mass is due to the momentum scale of 0.03 %

    D^0 mass : $0.09\,\mathrm{MeV/c^2}$
    mass difference : $0.04\,\mathrm{MeV/c^2}$

arXiv: 1304.6865

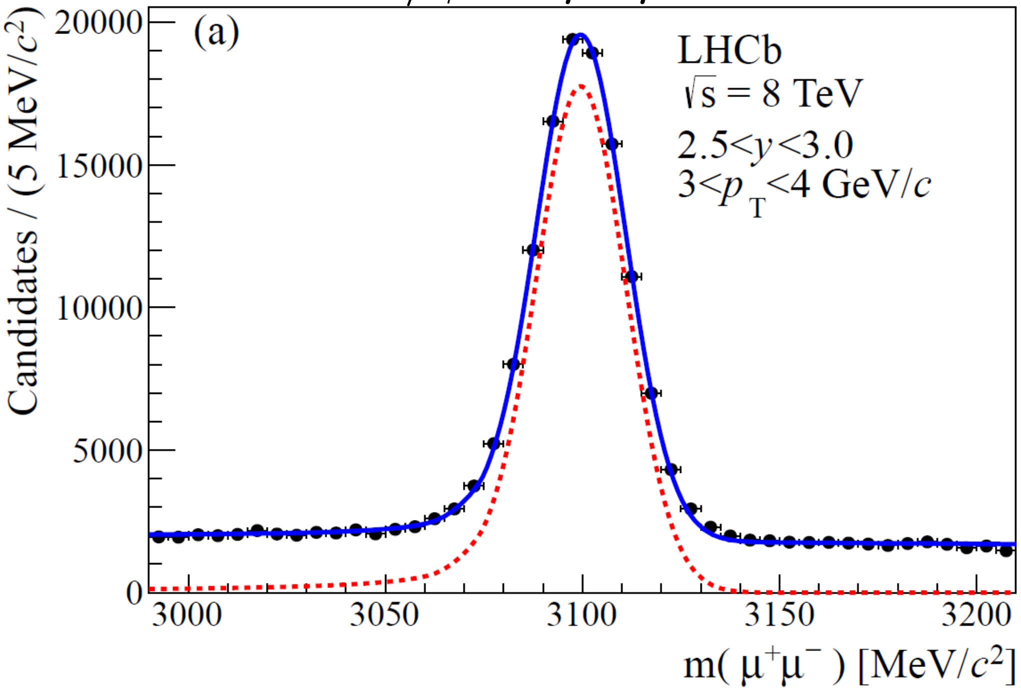




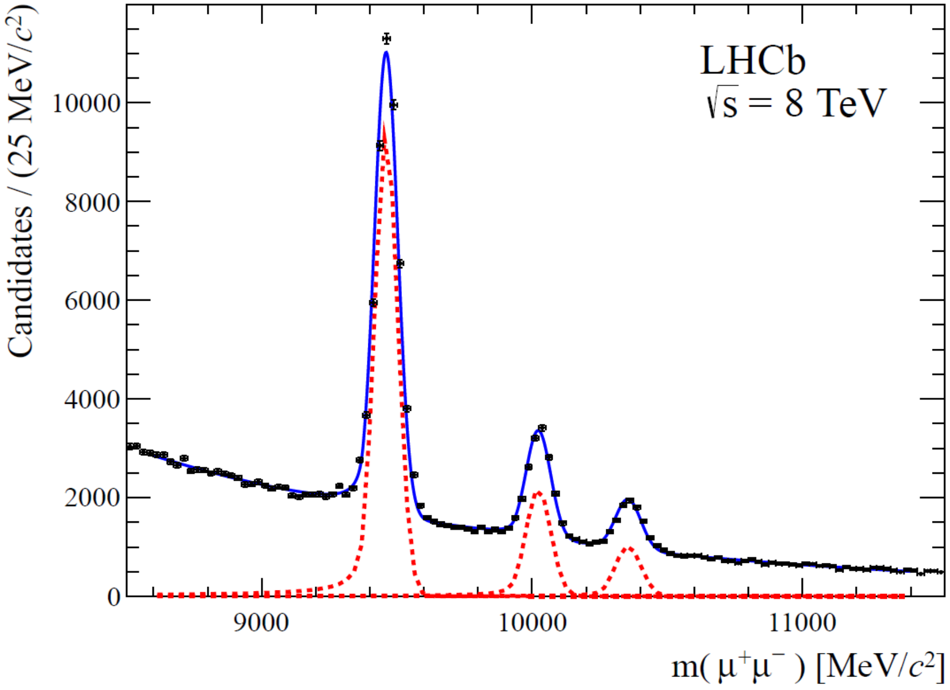
J/ψ and Υ Production in pp Collisions

- J/ψ , Υ production with $J/\psi \rightarrow \mu^+\mu^-$ and $\Upsilon(nS) \rightarrow \mu^+\mu^-$ at $\sqrt{s} = 8 TeV$
  $2.0 < y < 4.5$, $p_T(J/\psi) < 14\ GeV/c$, $p_T(\Upsilon) < 15\ GeV/c$ arXiv: 1304.6977

$J/\psi \rightarrow \mu^+\mu^-$



$\Upsilon(nS) \rightarrow \mu^+\mu^-$



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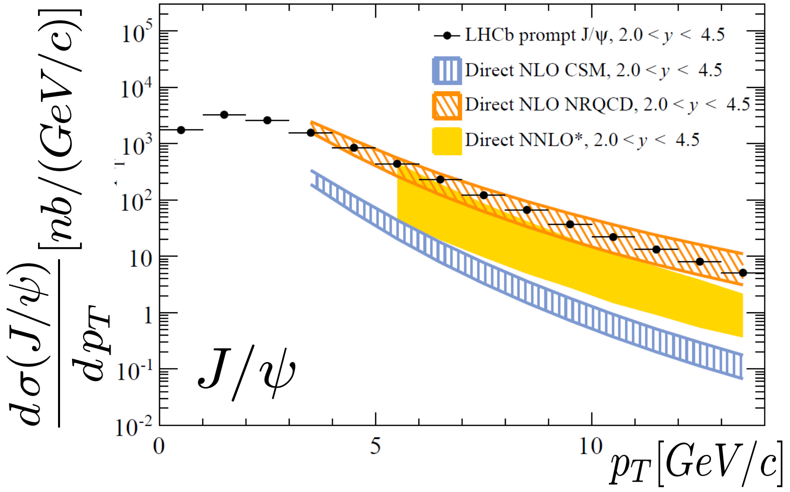
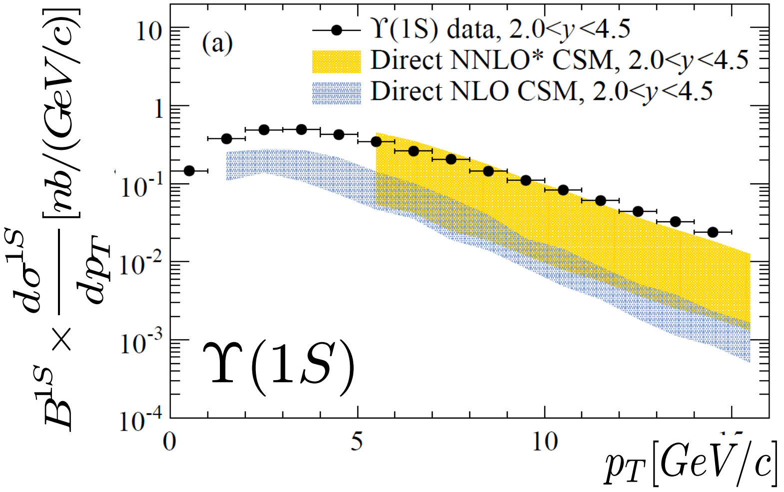
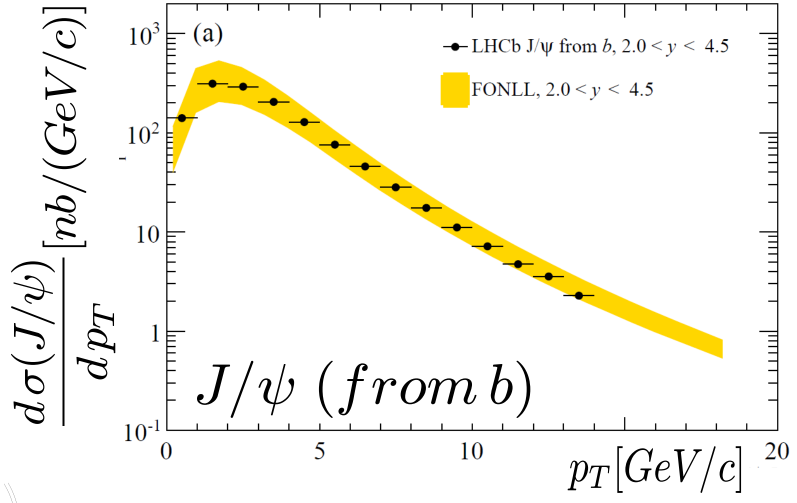
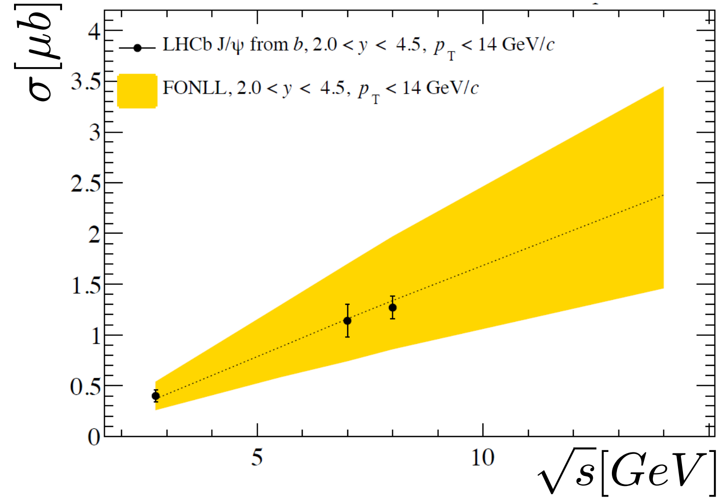


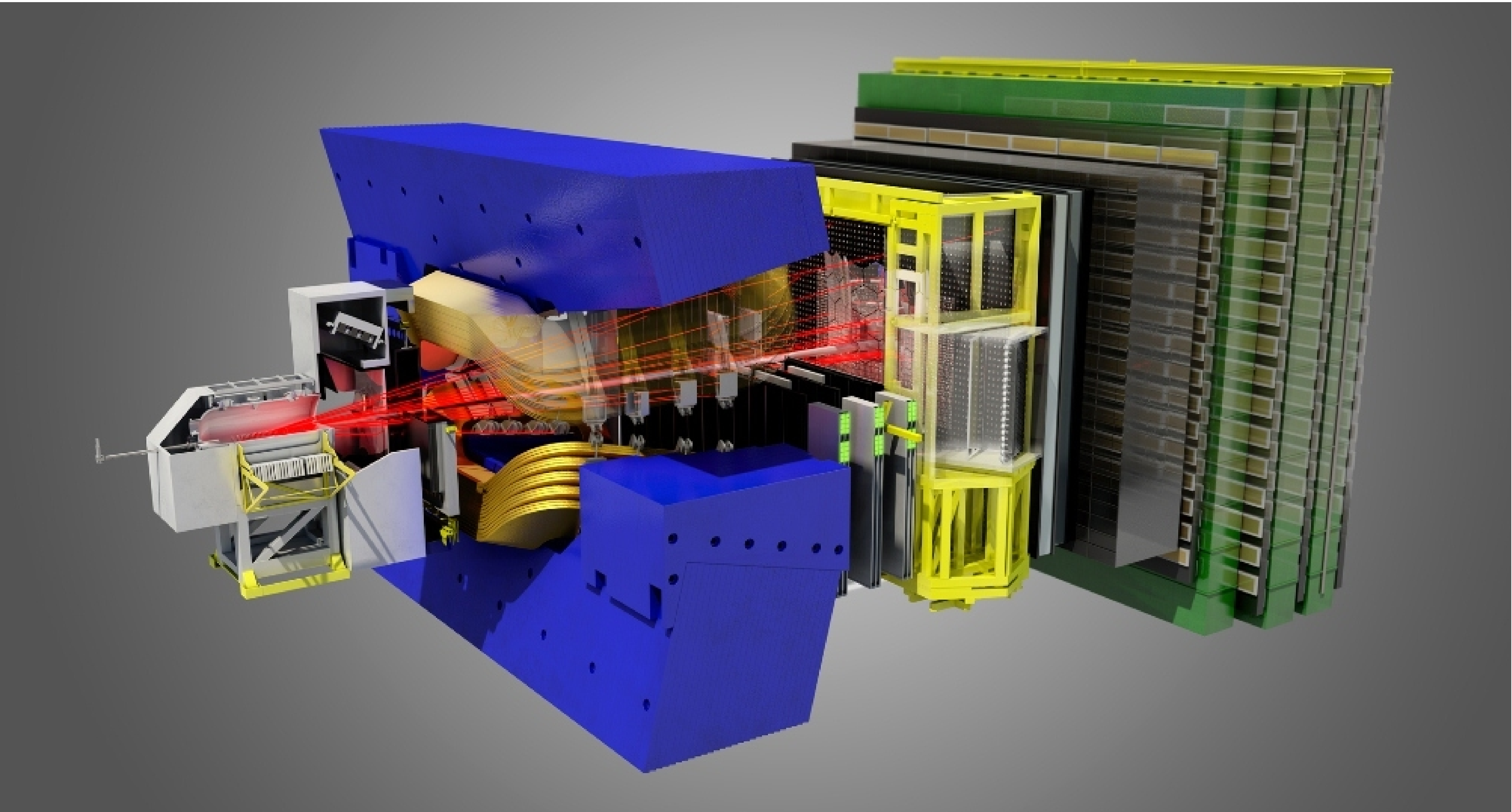






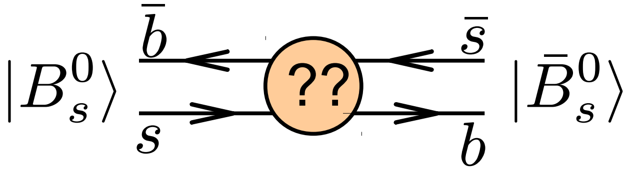
Selected results

Mixing and CP violation in the $B_{(s)}$ System



Mixing Formalism in Neutral Mesons

Neutral mesons (K, D, B, B_s) are created as flavor eigenstates of the strong interaction. They can mix through weak interactions.



- The time evolution is obtained by

$$i\frac{\partial}{\partial t}\begin{pmatrix} B_s^0(t) \\ \bar{B}_s^0(t) \end{pmatrix} = \left[\begin{pmatrix} M_{11} & M_{12} \\ M_{12}^* & M_{22} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{22} \end{pmatrix}\right]\begin{pmatrix} B_s^0(t) \\ \bar{B}_s^0(t) \end{pmatrix}$$

- The physical eigenstates are B_L^s and B_H^s:

$$|B_{L,H}^s\rangle = p|B_s^0\rangle \mp q|\bar{B}_s^0\rangle$$

$$|B_{L,H}^s(t)\rangle = e^{-i(M_{L,H} - i\Gamma_{L,H}/2)t}|B_{L,H}^s(t=0)\rangle$$

- Define mass and lifetime differences of B_L^s and B_H^s:

$$\boxed{x = \frac{\Delta M}{\Gamma} = \frac{M_H - M_L}{\Gamma} \qquad y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_H - \Gamma_L}{2\Gamma}}$$

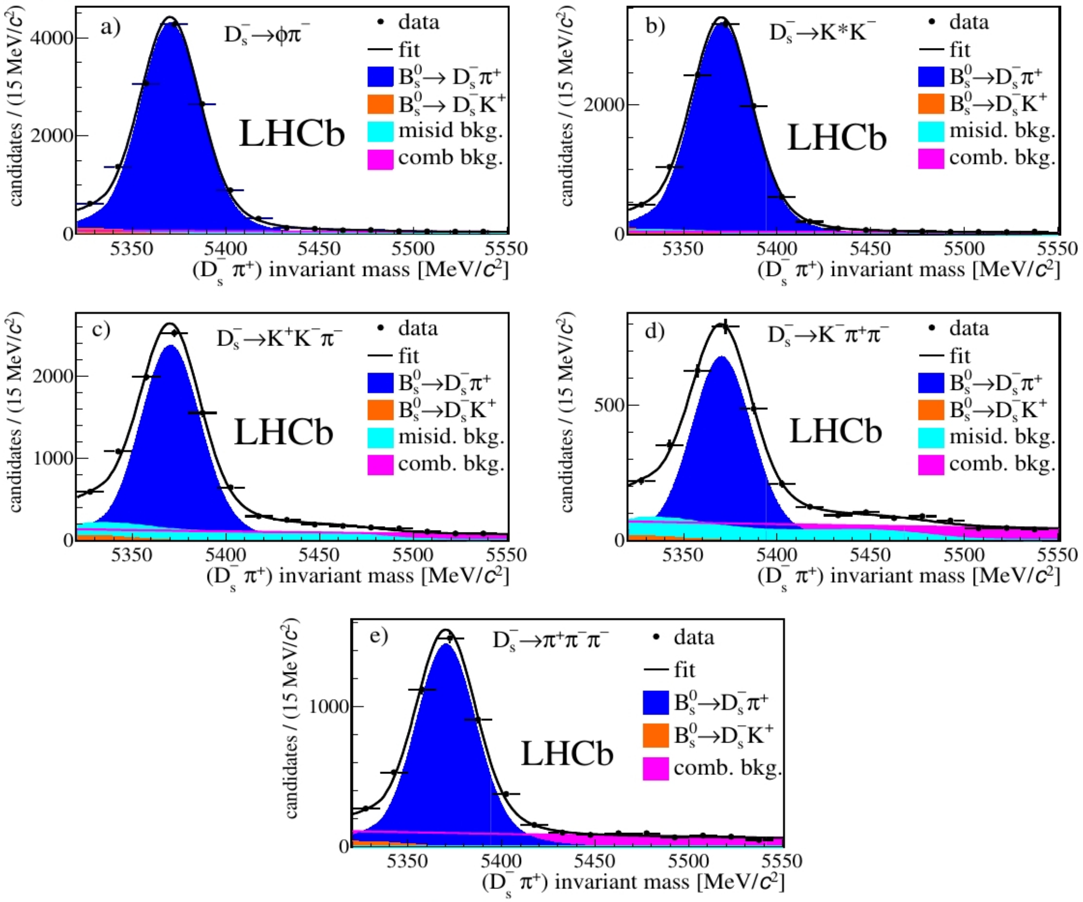
$$\Gamma = \frac{\Gamma_L + \Gamma_H}{2}$$

$B_s - \overline{B}_s$ Oscillation in $B_s \to D_s^- \pi^+$

Measure time dependent decay rate of $B_s \to D_s^- \pi^+$ and $\bar{B}_s \to D_s^+ \pi^-$

- Select 34 k $B_s \to D_s \pi$ candidates with 5 D_s decay modes in 1 fb^{-1}

NJOP 15, 053021 (2013)



$$D_s^- \to \phi(K^+K^-)\pi^-$$

$$D_s^- \to K^{*0}(K^+\pi^-)K^-$$

$$D_s^- \to K^+K^-\pi^- \ non-resonant$$

$$D_s^- \to K^-\pi^+\pi^-$$

$$D_s^- \to \pi^-\pi^+\pi^-$$

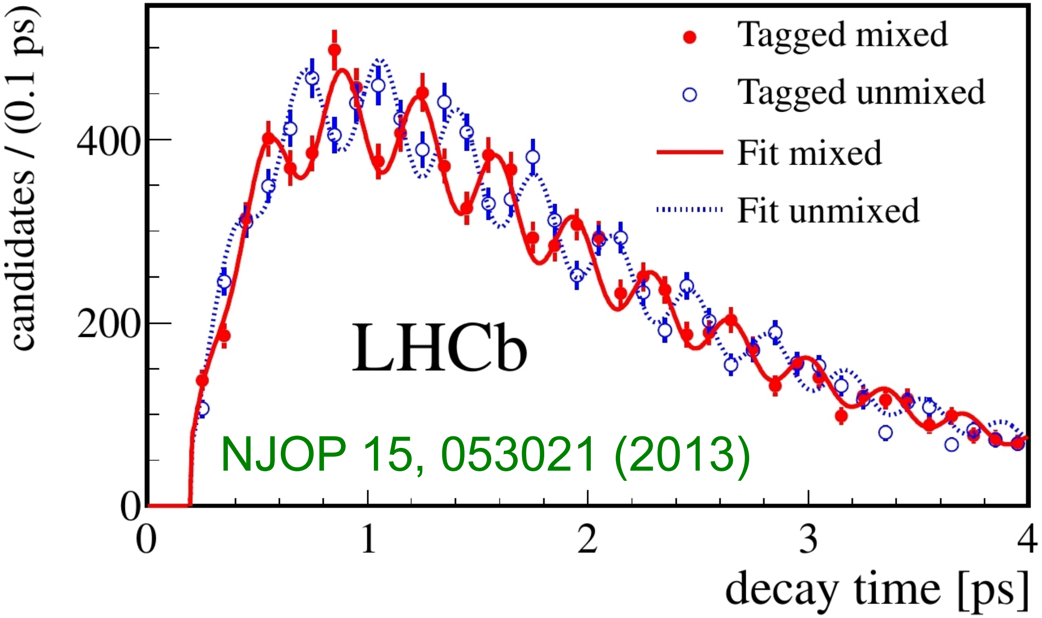
- Background separation in B_s mass
- Flavour tagging at production
- Flavour at decay from final state

Δm_s Measurement

- Perform unbinned max. likelihood fit in B_s mass and decay time
  - $PDF \propto \left[e^{-\Gamma t} \cdot \left(cosh\left(\frac{\Delta\Gamma}{2} t\right) \pm D\, cos(\Delta m\, t)\right)\right] \otimes R(\sigma_t)$

    flavour tagging

    event-by-event decay time resolution
  - Mean decay time resolution 44 fs
- Fit results



NJOP 15, 053021 (2013)

- Largest systematic uncertainty contributions: z – and p scale
- Most precise measurement of Δm_s to date
- Good agreement with current world average and SM

$$\Delta m_s = 17.768 \pm 0.023\,(stat) \pm 0.006\,(syst)\; ps^{-1}$$

CPV Measurements in the B System

The only source of CP violation in SM is a single complex phase in the CKM matrix.

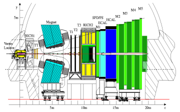
- CP violation in mixing, $q/p \neq 1$

$$a_{sl}^{s} = \frac{\Gamma(B_s^0 \to D_s^- \mu^+) - \Gamma(\bar{B}_s^0 \to D_s^+ \mu^-)}{\Gamma(B_s^0 \to D_s^- \mu^+) + \Gamma(\bar{B}_s^0 \to D_s^+ \mu^-)} \approx 1 - |q/p|^2$$

LHCb-CONF-2012-022
not discussed here

- CP violation in decay, $\Gamma(P \to f) \neq \Gamma(\bar{P} \to \bar{f})$
  - Asymmetries in B_d^0 , $B_s^0 \to K\pi$ decays arXiv:1304.6173
  - Asymmetries in $B \to h^+ h^- h^+$ decays arXiv:1306.1246

- CP violation in interference of mixing and decay
  - $\phi_s^{c\bar{c}s}$ in $B_s^0 \to J/\psi\phi$ and $B_s^0 \to J/\psi\pi\pi$ arXiv:1304.2600
  - $\phi_s^{s\bar{s}s}$ in $B_s^0 \to \phi\phi$ arXiv:1303.7125 not discussed here



CPV in Charmless 2-body B Decays

- The interference between $b \to u$ tree and $b \to d(s)$ penguin processes gives access to direct CP violation in $B^0_{(s)} \to K\pi$ decays
  - Measure the asymmetries

$$A_{CP} = \frac{N_{\bar{B}\to\bar{f}} - N_{B\to f}}{N_{\bar{B}\to\bar{f}} + N_{B\to f}} \qquad B \to f = \begin{pmatrix} B^0 \to K^+\pi^- \\ B^0_s \to K^-\pi^+ \end{pmatrix}$$

  - First measurements in $B^0 \to K^+\pi^-$ by BABAR and Belle (2004)
  - Test Standard Model prediction in a model independent way by

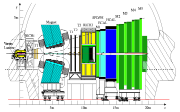
$$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B^0_s \to K^-\pi^+)} + \frac{\mathcal{B}(B^0_s \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)}\frac{\tau_d}{\tau_s} \underbrace{\equiv}_{\text{SM}} 0$$

H.J. Lipkin, Phys. Lett. B 621 (2005) 126

arXiv:1304.6173

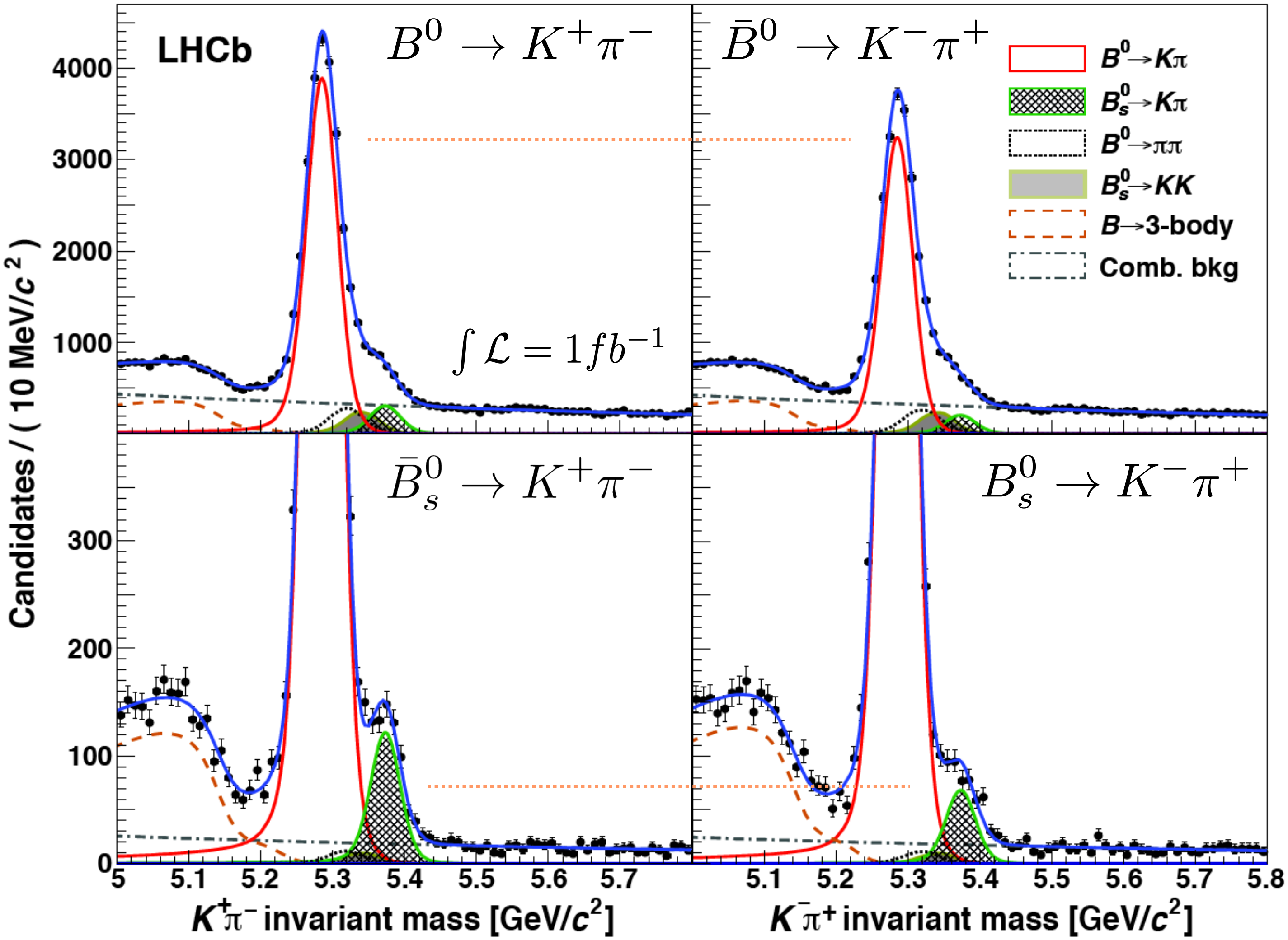
arXiv:1206.2794

HFAG averages



$B_{(s)} \rightarrow K\pi$ Signal

arXiv:1304.6173



$B^0 \rightarrow K\pi$:

$N_{sig} = 41420 \pm 300$

$B^0_s \rightarrow K\pi$:

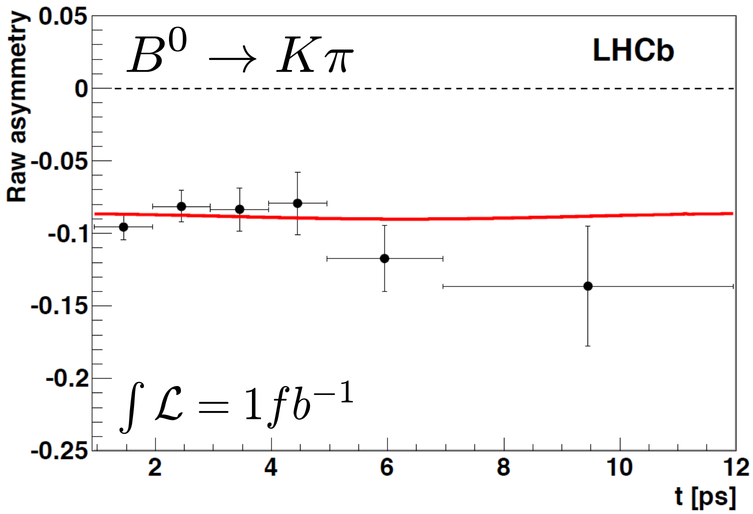
$N_{sig} = 1065 \pm 55$

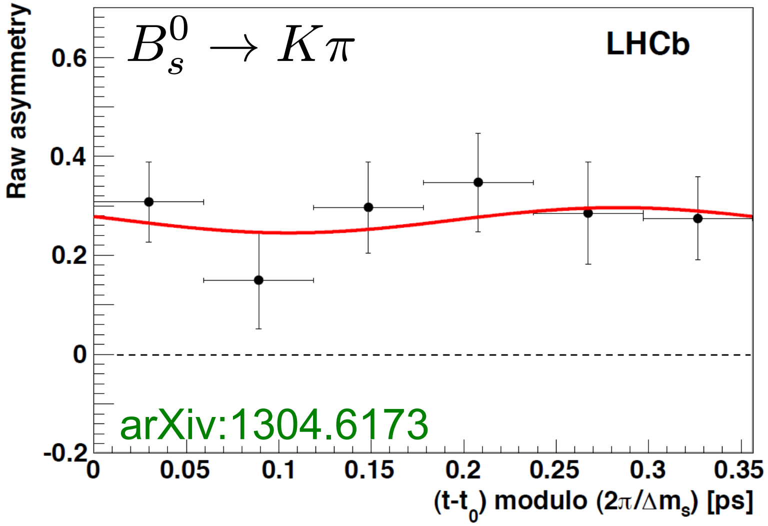
mass resolution:

$\sigma(m) = 22\ MeV$

Results - CPV in $B_{(s)} \to K\pi$

- Raw asymmetry measurements





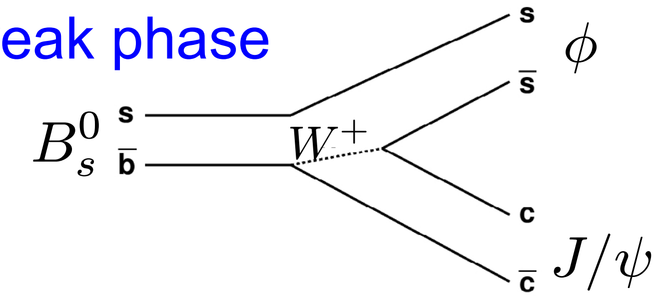
arXiv:1304.6173

- Results after correcting for detection and production asymmetries
  - $A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.04\,(stat)\ \pm 0.01\,(sys)$

    Significance = $6.5\,\sigma$ (first observation)
  - $A_{CP}(B^0 \to K^+\pi^-) = -0.08 \pm 0.007\,(stat)\ \pm 0.003\,(sys)$

    significance = $10.5\,\sigma$
  - $\Delta = -0.02 \pm 0.05 \pm 0.04 \quad \to$ compatible with SM expectation

ϕ_s Measurement in $B_s \to J/\psi\phi$



- $B_s^0 \to J/\psi\phi$ is a tree dominated decay with a weak phase

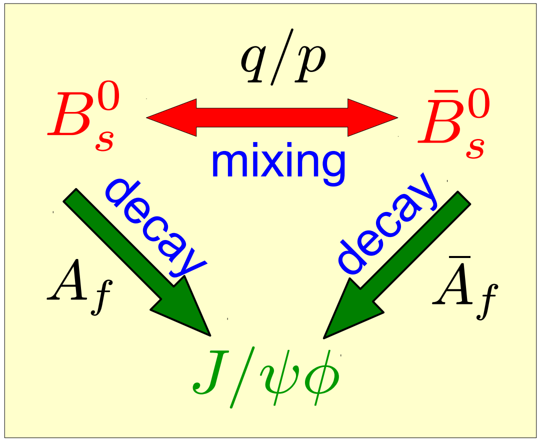
  $\phi_D = arg(V_{cs}V_{cb}^*)$

- $B_s - \bar{B}_s$ oscillation leads to the weak phase

  $\phi_M = 2\, arg(V_{ts}V_{tb}^*)$

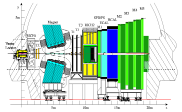
- Access the CP violating phase via the interfering amplitudes of $B_s^0 \to J\psi\phi$ and $B_s^0 \to \bar{B}_s^0 \to J\psi\phi$
  - $\phi_{J/\psi\phi} \equiv \phi_s = \phi_D - 2\,\phi_M \underbrace{\equiv}_{\text{in SM}} \phi_s^{SM}$
  - Get ϕ_s^{SM} from global fit ignoring penguin contribution, CKM fitter, arXiv:1106.4041

    $\phi_s^{SM} = 0.0364 \pm 0.0016\, rad$



- Access new physics contributions by deviations from SM

  $\phi_s = \phi_s^{SM} + \Delta\phi_s \;, \quad \Delta\phi_s = arg(M_{12}/M_{12}^{SM})$



CPV and $\Delta\Gamma_s$ in $B_s \to J/\psi\phi$

- Need an angular analysis to statistically separate CP eigenstates

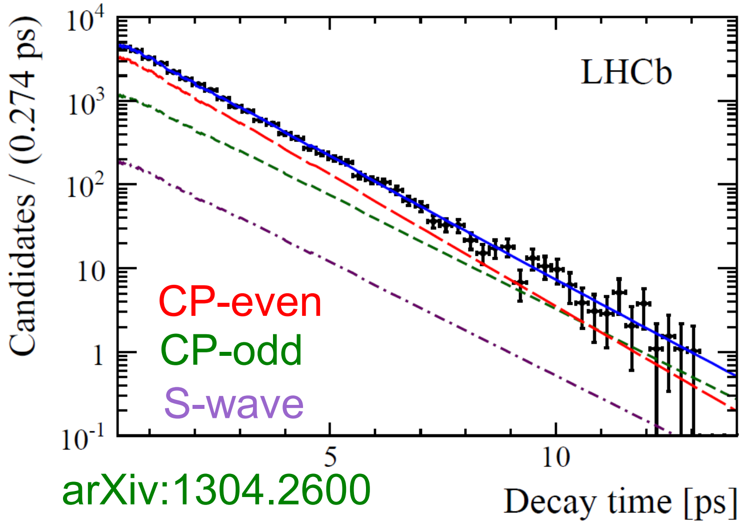
$\phi \to K^+K^-$ in P wave → CP-even, CP-odd
$\phi \to K^+K^-$ in S wave → CP-odd
depending on rel. orbital
momentum of J/ψ and ϕ

helicity angles $\Omega = (\theta_\mu, \theta_K, \phi_h)$

- Use an sWeight-based method to determine in an max. likelihood fit to $\frac{d^4\Gamma(B_s^0 \to J\psi KK)}{dt\, d\Omega}$ the physics quantities $\phi_s\,,\ \Delta\Gamma_s\,,\ \Gamma_s\,,\ ....$

- Key ingredients to t – dependent flavour tagged angular analysis

  - probability of getting the initial B flavour wrong
  - decay time measurement
  - event by event decay time resolution
  - knowledge of Δm_s



arXiv:1304.2600

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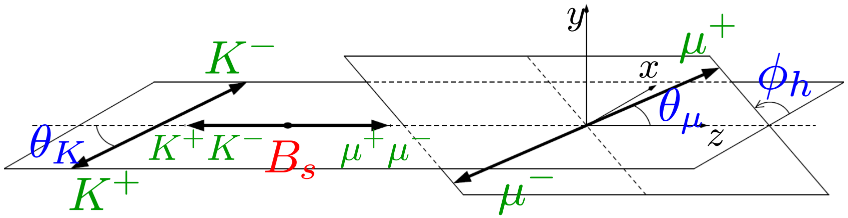

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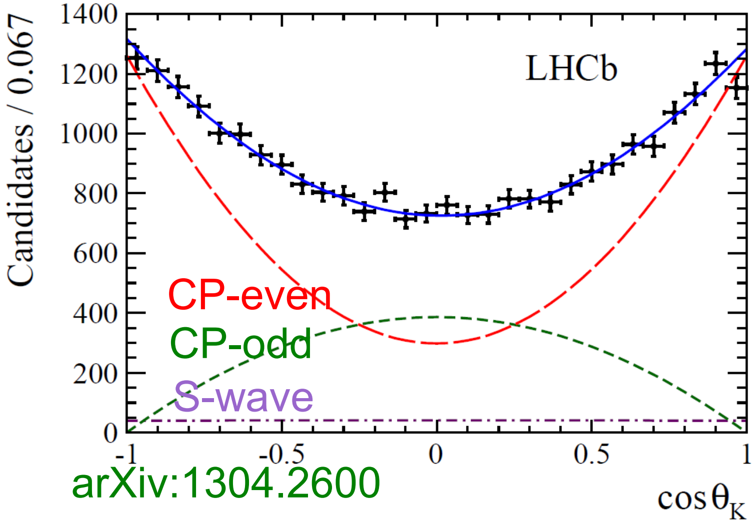
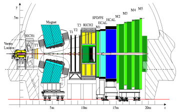


arXiv:1304.2600



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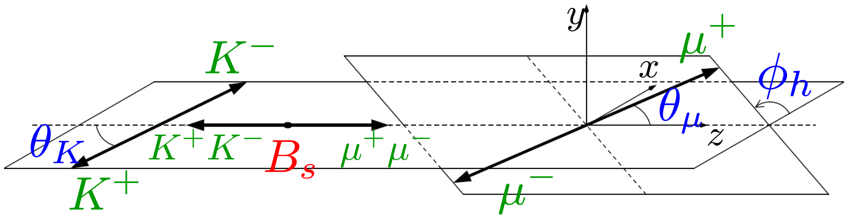

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  - event by event decay time resolution
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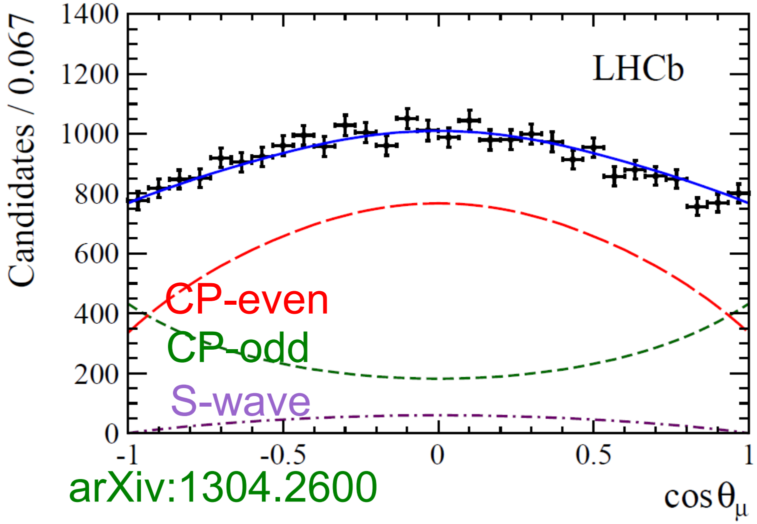

arXiv:1304.2600

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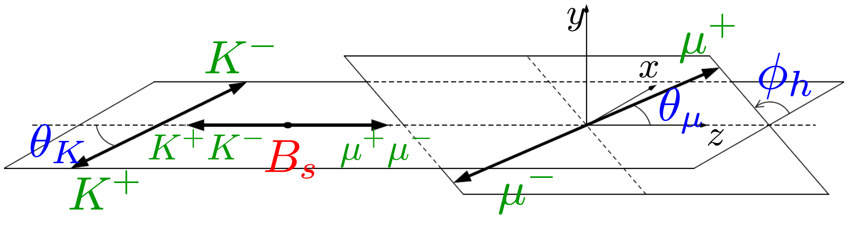

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- decay time measurement

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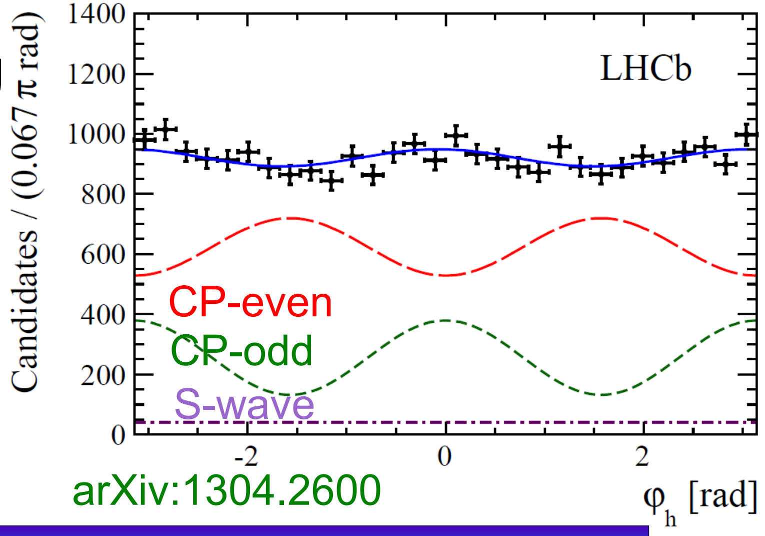
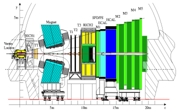


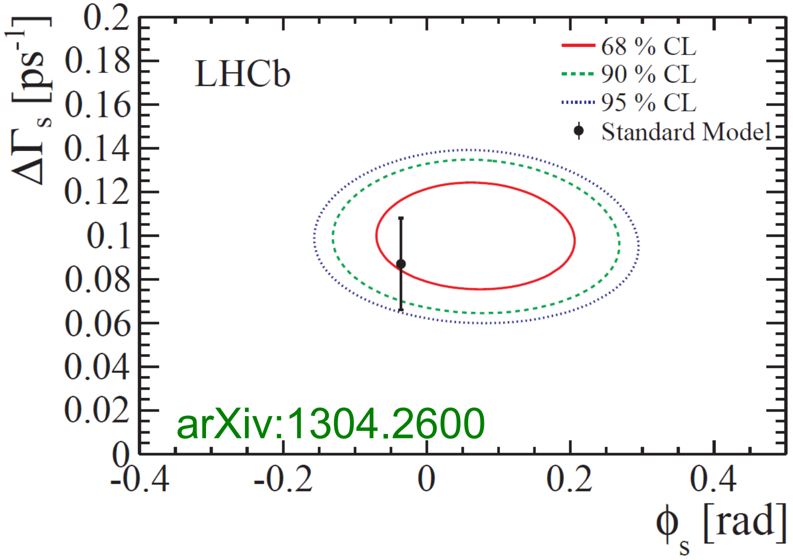
arXiv:1304.2600



Results - ϕ_s , $\Delta\Gamma_s$ in $B_s \to J/\psi\phi$

- Results for $B_s \to J/\psi\phi(K^+K^-)$

$$\begin{aligned}\phi_s &= 0.07 \pm 0.09 \pm 0.01\, rad \\ \Delta\Gamma_s &\equiv \Gamma_L - \Gamma_H \\ &= 0.100 \pm 0.016 \pm 0.003\, ps^{-1} \\ \Gamma_s &\equiv (\Gamma_L + \Gamma_H)/2 \\ &= 0.663 \pm 0.005 \pm 0.006\, ps^{-1}\end{aligned}$$



arXiv:1304.2600

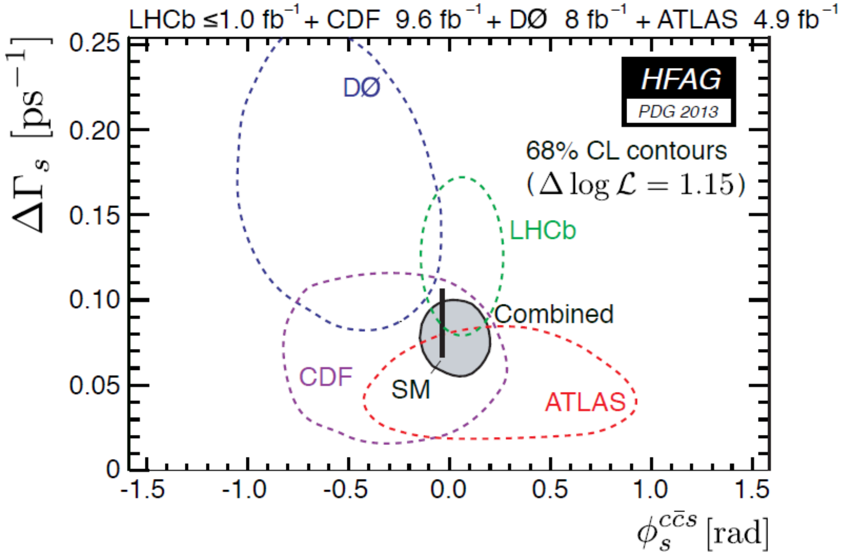
Good agreement with Standard Model expectations

This measurement superceeds previous LHCb results.

- Combined with $B_s \to J/\psi\phi(\pi^+\pi^-)$

$$\begin{aligned}\phi_s &= 0.01 \pm 0.07 \pm 0.01\, rad \\ \Delta\Gamma_s &= 0.106 \pm 0.011 \pm 0.007\, ps^{-1} \\ \Gamma_s &= 0.661 \pm 0.004 \pm 0.006\, ps^{-1}\end{aligned}$$

- HFAG average for $\phi_s^{c\bar{c}s}$ vs $\Delta\Gamma_s$



CPV in $B^\pm \to K^\pm\pi^+\pi^-$ and $B^\pm \to K^\pm K^+K^-$

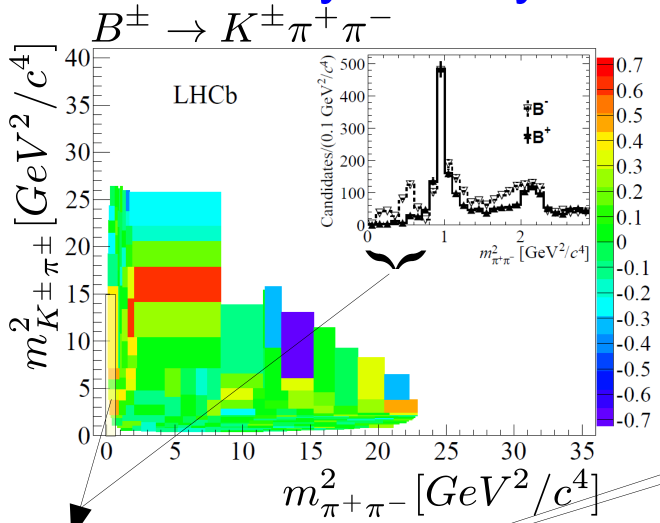
- First evidence of an inclusive CP asymmetry in charmless 3-body decays

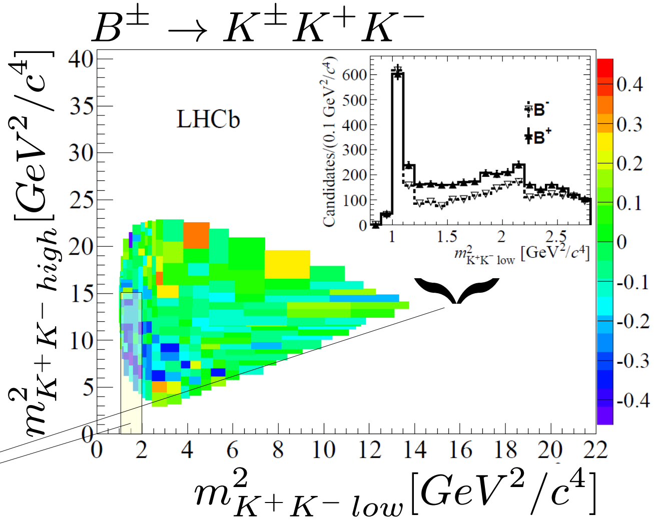
$$A_{CP}(B^\pm \to K^\pm\pi^+\pi^-) = 0.032 \pm 0.008 \pm 0.004 \pm 0.007$$

$$A_{CP}(B^\pm \to K^\pm K^+K^-) = -0.043 \pm 0.009 \pm 0.003 \pm 0.007$$

significance: 2.8σ 3.7σ

- Local CP asymmetry





arXiv:1306.1246

binned asymmetry:

$$A^N_{CP} = \frac{N(B^-) - N(B^+)}{N(B^-) + N(B^+)}$$

$$A^{reg}_{CP}(K\pi\pi) = +0.678 \pm 0.078 \pm 0.032 \pm 0.007$$

$$A^{reg}_{CP}(KKK) = -0.226 \pm 0.020 \pm 0.004 \pm 0.007$$

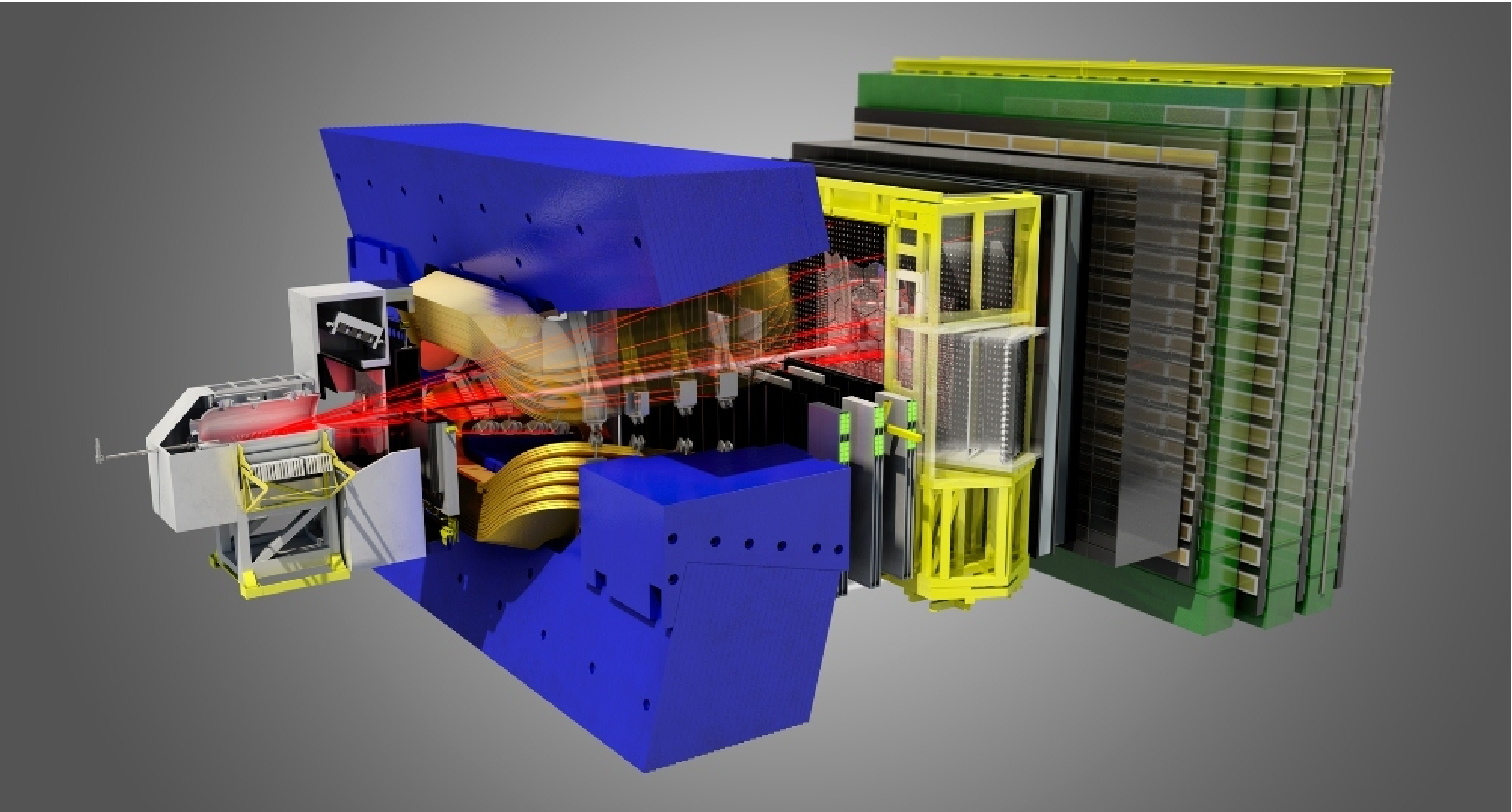
$$N^{reg}_{excess}(K\pi\pi) \approx -N^{reg}_{excess}(KKK)$$

Final state rescattering between 2 or more decay channels with the same flavour quantum numbers could enhance CP asymmetries.

H.-Y. Cheng et al., Phys.Rev. D71, (2005) 014030

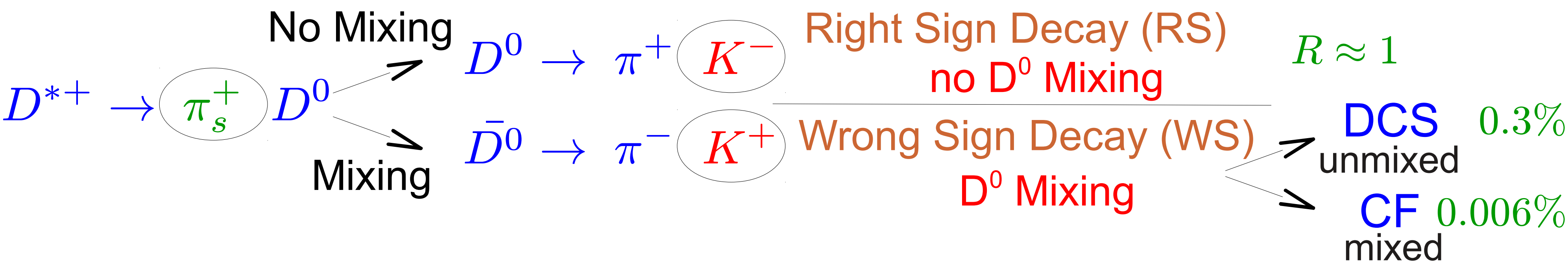
Selected results

Mixing and CP violation in Charm



D Mixing in $D^0 \to K\pi$ Decays

- Event classes - flavour tagging at production and decay



No Mixing

$D^{*+} \to \pi_s^+ D^0$

Mixing

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

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

Right Sign Decay (RS)

no D⁰ Mixing

$R \approx 1$

Wrong Sign Decay (WS)

D⁰ Mixing

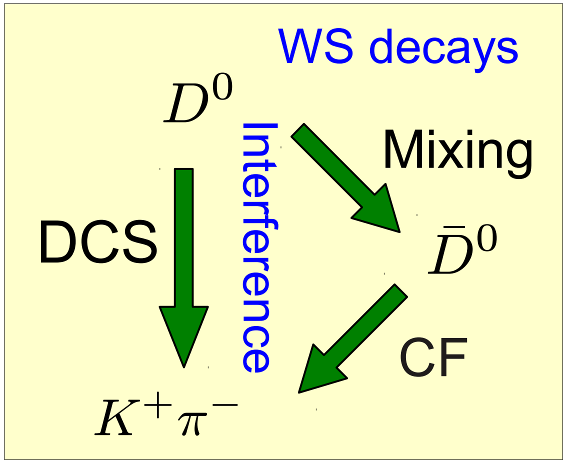
DCS 0.3%

unmixed

CF 0.006%

mixed

- Time evolution of the WS decay rate



- assume CP conservation and $|x| \ll 1\ ;\ |y| \ll 1$

$$T_{WS}(t) \propto e^{-\Gamma t} \left(\underbrace{R_D}_{\text{DCS}} + \underbrace{\sqrt{R_D}\, y'\, \Gamma t}_{\text{Interference}} + \underbrace{\frac{x'^2 + y'^2}{4} (\Gamma t)^2}_{\text{Mixing}} \right)$$

- $\delta_{K\pi}$ is the strong phase between CF and DCS amplitudes ($D^0 \to K\pi$)

$$\begin{aligned} x' &= \quad x \cos \delta_{K\pi} + y \sin \delta_{K\pi} \\ y' &= -x \sin \delta_{K\pi} + y \cos \delta_{K\pi} \end{aligned}$$

$$y'^2 + x'^2 = x^2 + y^2$$

Mixing in t-dependent WS $D^0 \to K\pi$

arXiv:1211.1230

- Measure the Number of WS and RS D^0 decays in 13 bins of the lifetime.

$$N_{RS}^{tot} = 8.4 \cdot 10^6 \qquad N_{WS}^{tot} = 3.6 \cdot 10^4$$

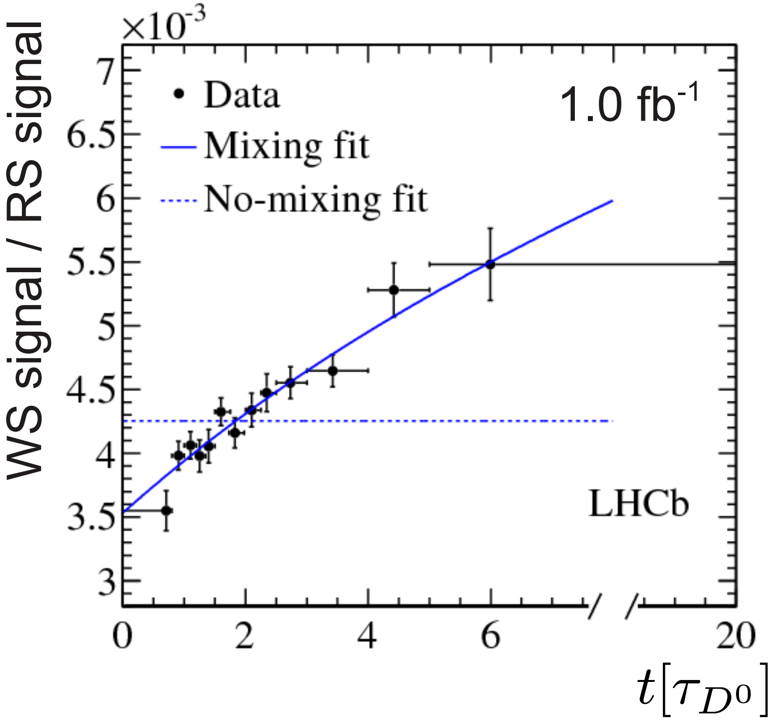
- Fit the $N_{WS}^{tot}/N_{RS}^{tot}$ vs the D^0 decay time

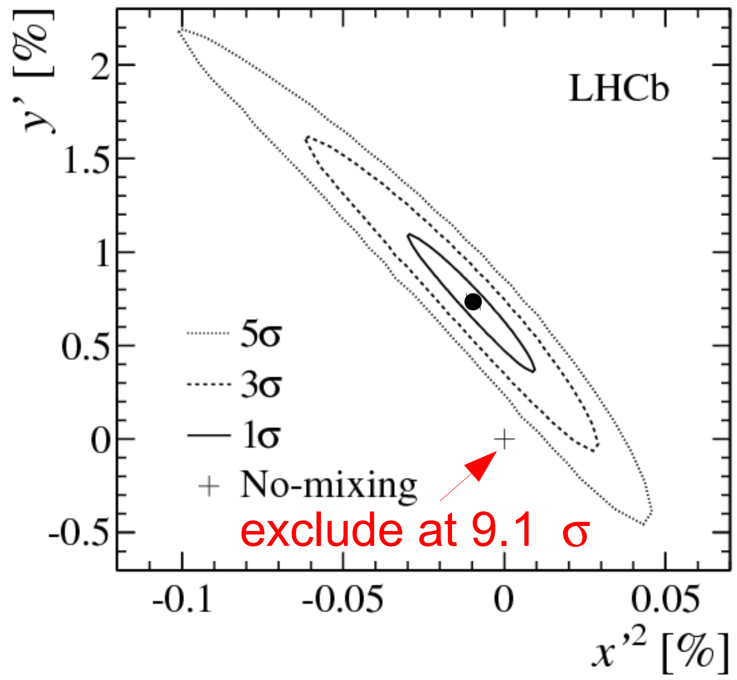
$$R(t) \propto e^{-\Gamma t}\left(R_D + \sqrt{R_D}\, y'\, \Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2\right)$$

- Mixing Parameter

$$R_D = (0.352 \pm 0.015)\%$$
$$y' = (0.72 \pm 0.24)\%$$
$$x'^2 = (-0.009 \pm 0.013)\%$$

Errors include sys. uncertainties





exclude at 9.1 σ

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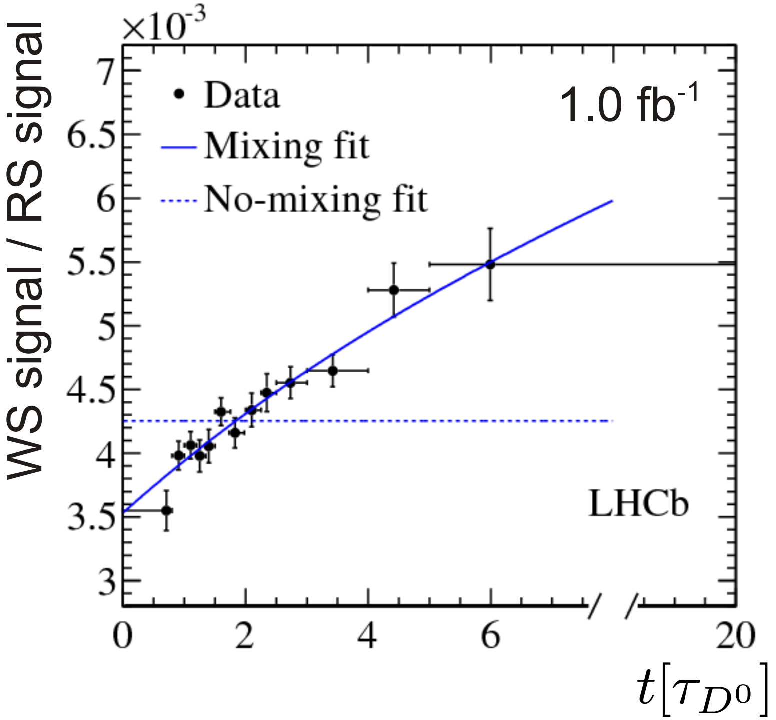

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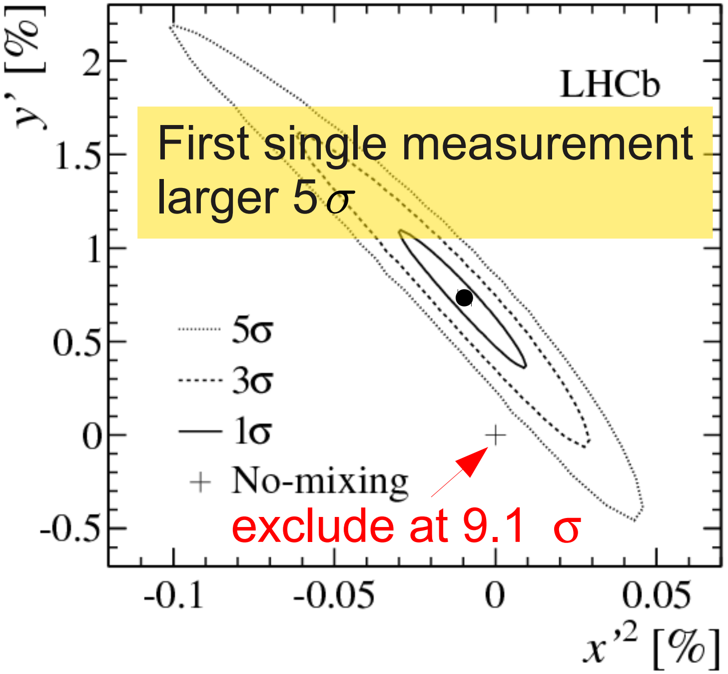


First single measurement larger 5 σ

exclude at 9.1 σ

CPV in D Decays

In the Standard Model CP violating effects are predicted to be small $(\sim 10^{-3})$

- Access CP violation through asymmetry measurements

$$A_{CP}(f;t) \equiv \frac{\Gamma(D^0(t)\to f) - \Gamma(\bar{D}^0(t)\to f)}{\Gamma(D^0(t)\to f) + \Gamma(\bar{D}^0(t)\to f)} = \underbrace{a^{dir}_{CP}(f)}_{\text{CPV in decay}} + \underbrace{\frac{t}{\tau} a^{ind}_{CP}}_{\text{CPV in mixing + interfer.}}$$

CP eigenstate

- Measure time integrated A_{CP} difference for $f = K^+K^-$ and $f = \pi^+\pi^-$

$$\begin{aligned}\Delta A_{CP} &= A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)\\ &= [a^{dir}_{CP}(K^+K^-) - a^{dir}_{CP}(\pi^+\pi^-)] + \frac{\Delta < t >}{\tau} a^{ind}_{CP}\end{aligned}$$

  - Measurements with 2 independent data samples in $\int \mathcal{L} = 1 fb^{-1}$

    - $D^{*+} \to D^0\pi^+$ decays: published, $\int \mathcal{L} = 0.6 fb^{-1}$: arXiv:1112.0938
      update preliminary, $\int \mathcal{L} = 1 fb^{-1}$: LHCb-CONF-2013-003
    - $B \to D^0\mu^-\nu_\mu X$ decays: arXiv:1303.2614

- ΔA_{CP} measurements in $D^+ \to \phi\pi^+$ and $D_s^+ \to K_s^0\pi^+$ are compatible with 0 arXiv:1303.4906, not discussed here

Results - ΔA_{CP} in $D^0 \rightarrow h^+ h^-$

LHCb results

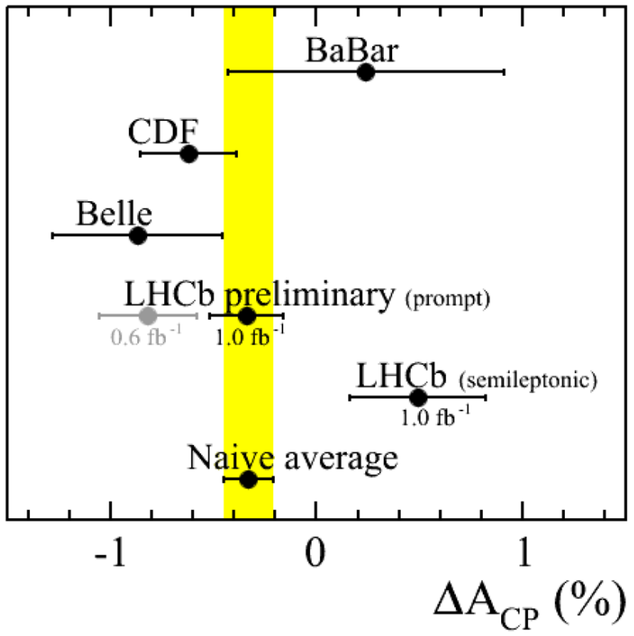
- D^* tagged sample (preliminary)

  $$\Delta A_{CP} = (-0.34 \pm 0.15\,(stat) \pm 0.10\,(sys))\ \%$$

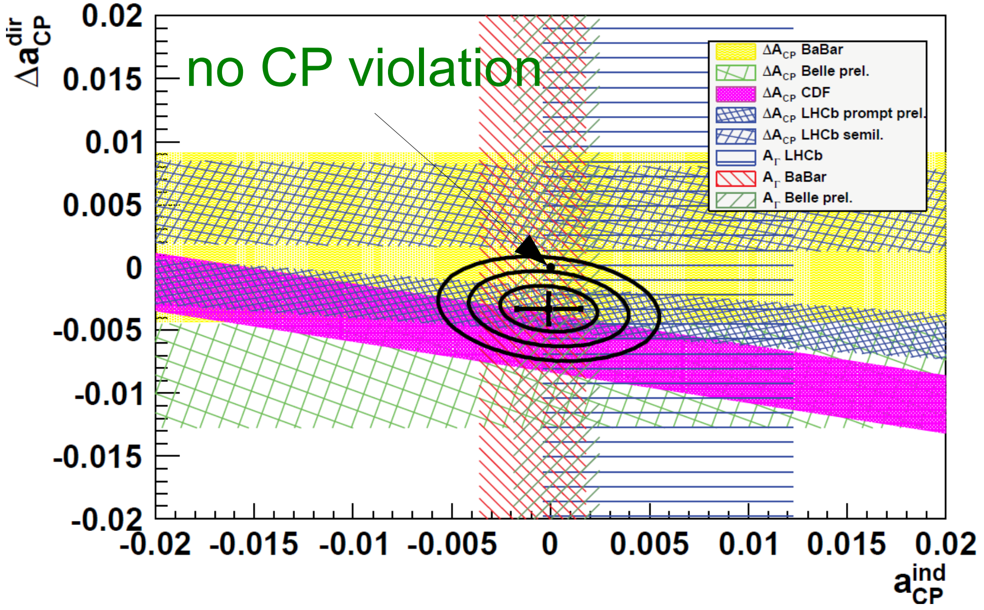
- μ tagged sample

  $$\Delta A_{CP} = (+0.49 \pm 0.30\,(stat) \pm 0.14\,(sys))\ \%$$

Consistent with no CP violation hypothesis



HFAG averages

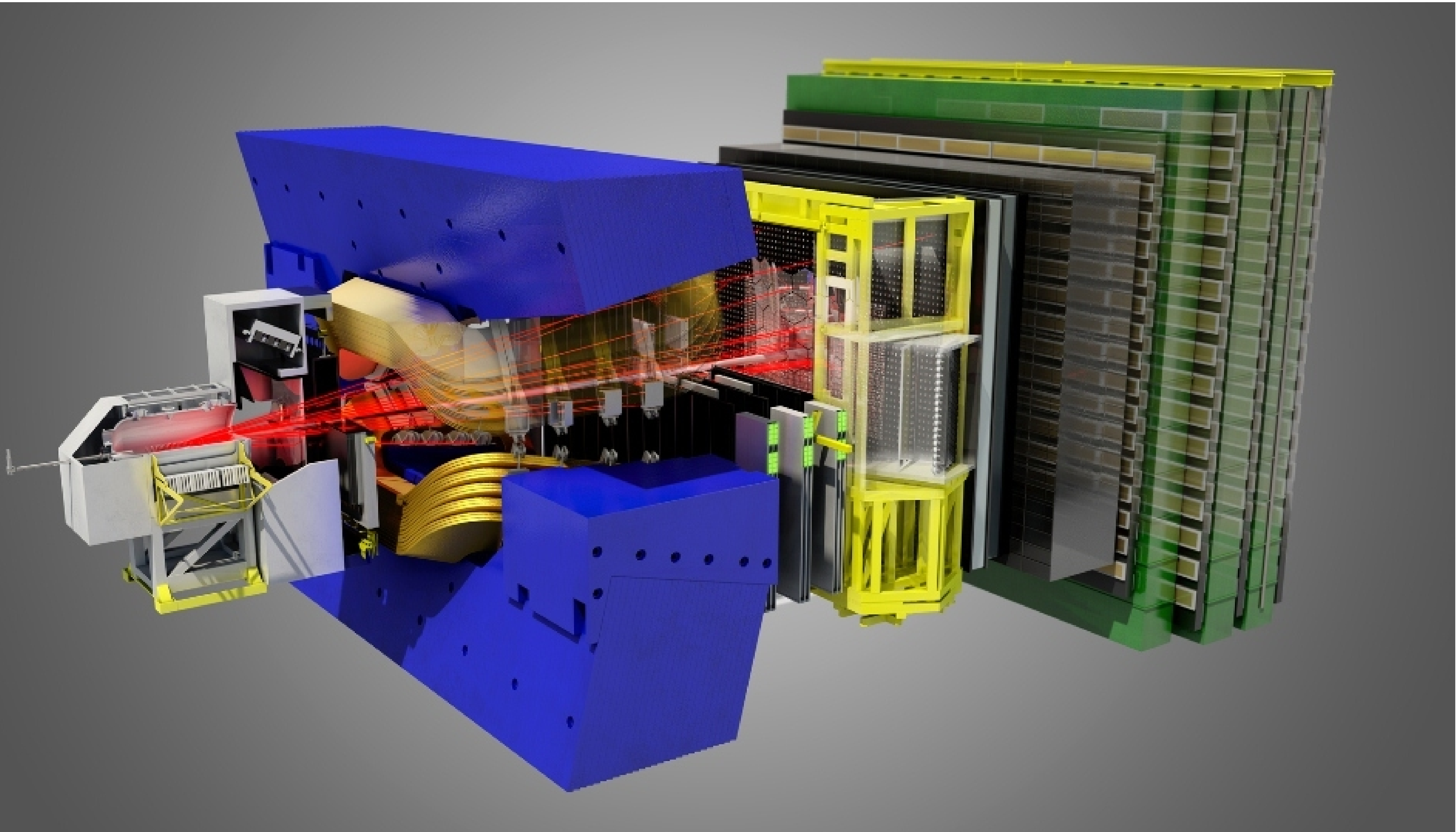


$$a_{CP}^{ind} = (-0.010 \pm 0.162)\ \%$$

$$\Delta a_{CP}^{dir} = (-0.329 \pm 0.121)\ \%$$

Selected results

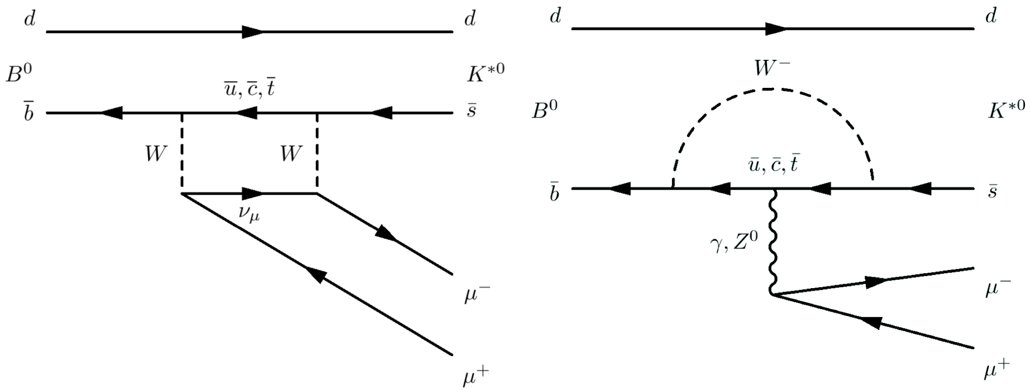
Rare Decays



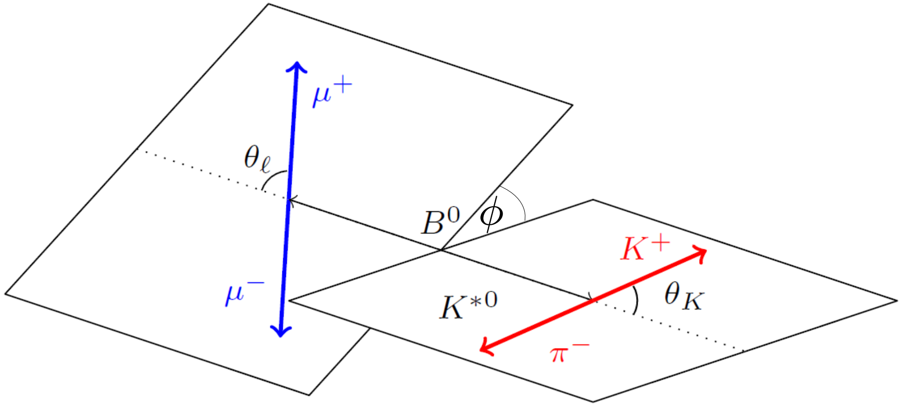
$b \to s l^+ l^-$ Decays

$b \to s l^+ l^-$ FCNC processes give access to physics contributions beyond SM

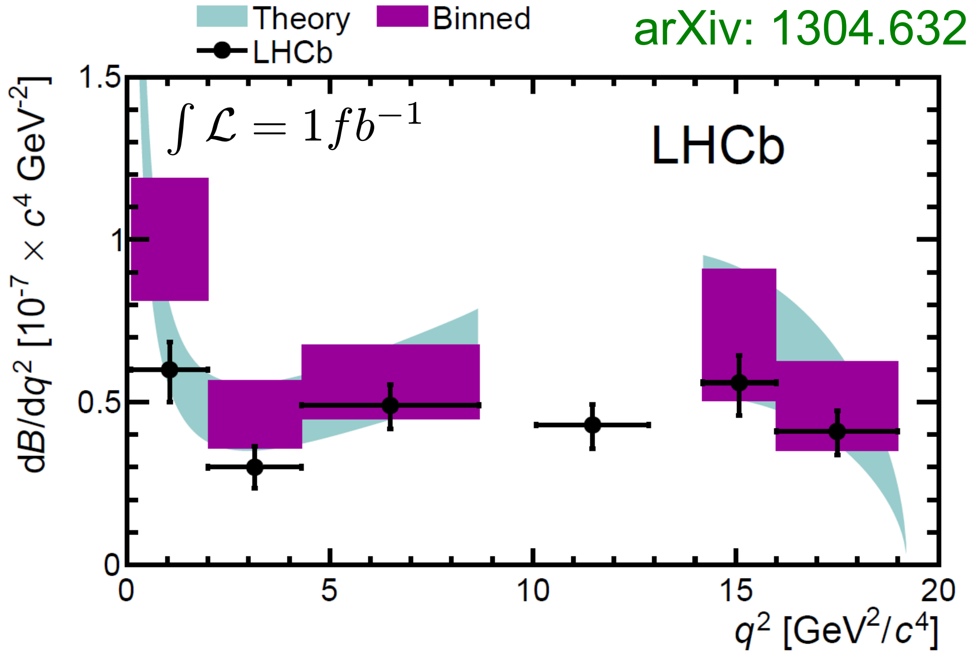
- $B^0 \to K^*(K^+\pi^-)\mu^+\mu^-$



- Angular definition θ_l, θ_K, ϕ



- Diff. branching fraction $B^0 \to K^*\mu^+\mu^-$

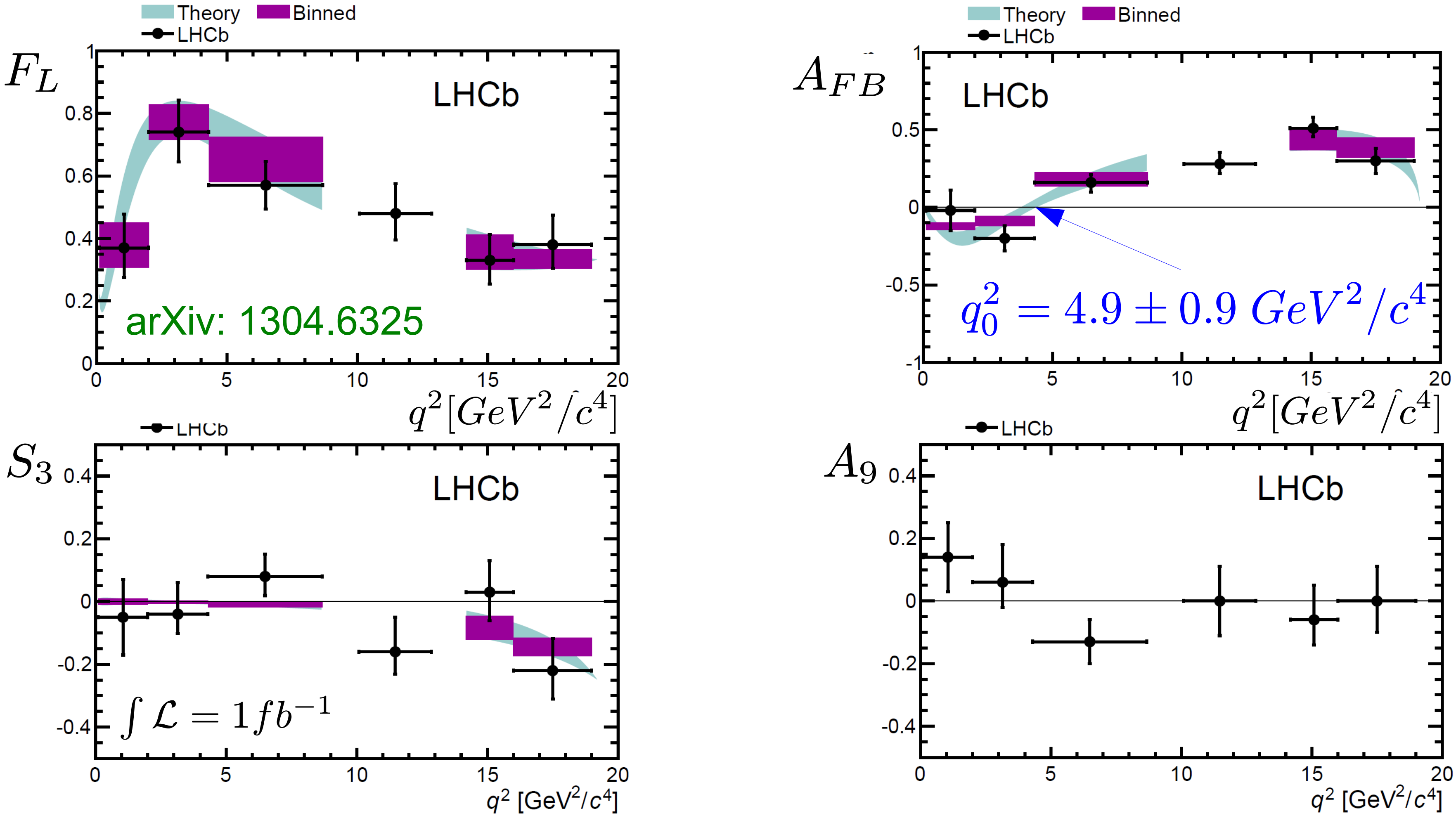


arXiv: 1304.6325

- Analyse $$\frac{d^4(\Gamma + \overline{\Gamma})}{dcos\theta_l \; dcos\theta_K \; d\phi \; dq^2}$$ and access angular observables F_L, A_{FB}, S_3, A_9 in bins of q^2

$B^0 \rightarrow K^* \mu^+ \mu^-$ Angular Observables

- Unbinned maximum likelihood fits to the differential decay rate



arXiv: 1304.6325

$q_0^2 = 4.9 \pm 0.9\ GeV^2/c^4$

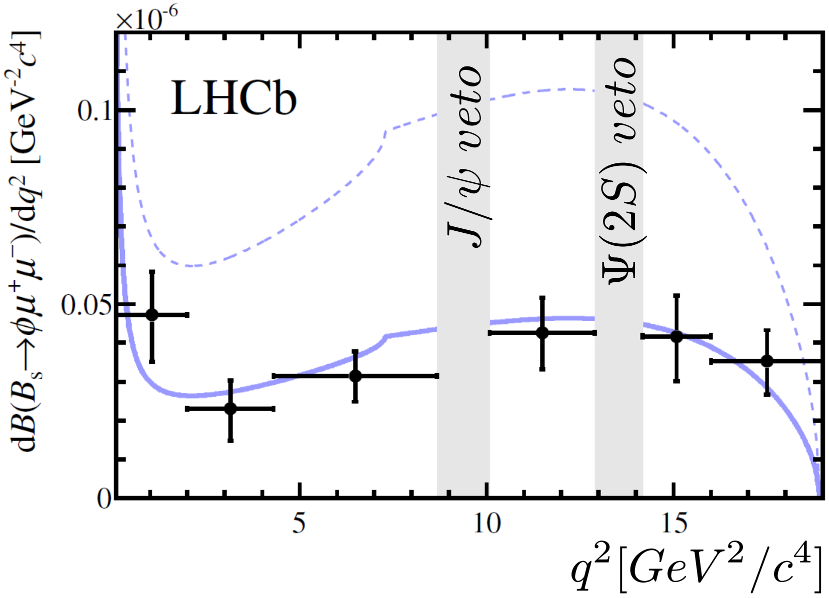
$\int \mathcal{L} = 1 fb^{-1}$

First measurement of $A_{FB}(q_0^2)$, consitent with leading order SM expectation

$B_s \to \phi\mu^+\mu^-$ Decays

$B_s^0 \to \phi(K^+K^-)\mu^+\mu^-$ decays are treated similar to $B^0 \to K^*\mu^+\mu^-$

- Differential branching fraction $B_s^0 \to \phi\mu^+\mu^-$ in bins of q^2



arXiv: 1305.2168
$(\int \mathcal{L} = 1fb^{-1})$

- Leading order SM calculations:

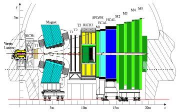
$(14.5 - 19.2) \times 10^{-7}$ (errors 20 - 30 %)

shape described

$$\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-) = (7.07^{+0.64}_{-0.59}(stat) \pm 0.17(sys) \pm 0.71(\mathcal{B})) \times 10^{-7}$$

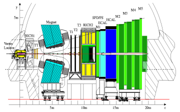
- Analyse $\frac{d^2(\Gamma+\bar{\Gamma})}{dcos\theta_K\ dq^2}$, $\frac{d^2(\Gamma+\bar{\Gamma})}{dcos\theta_l\ dq^2}$, $\frac{d^2(\Gamma+\bar{\Gamma})}{d\Phi\ dq^2}$ and access angular observables F_L, S_3, A_6, A_9 in bins of q^2

first measurement,
consistent with SM expectation

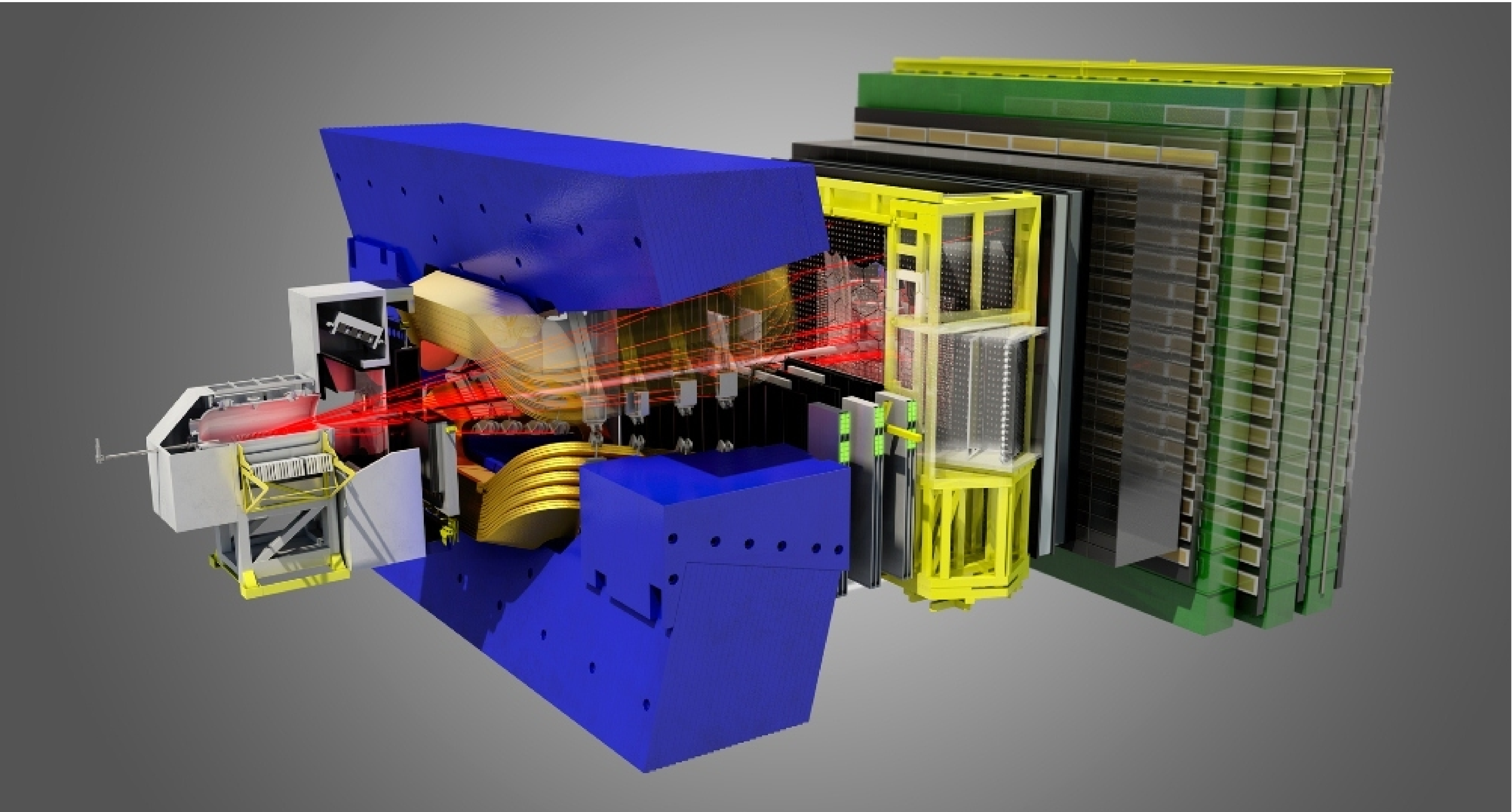


Summary

- LHCb, the forward spectrometer at the LHC, enters the high precision domain of flavour physics as demonstrated here with selected results
- Standard Model still holds its ground, LHCb does not observe tensions in the numerous measurements performed
- Measurements presented here use mainly the 2011 dataset, 30 % of the full dataset, so many more exciting results from LHCb are expected



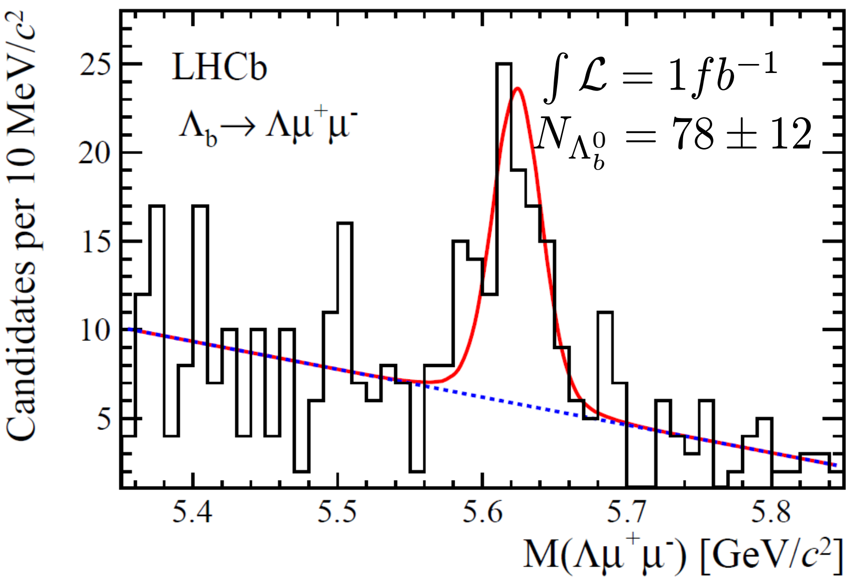
Back up

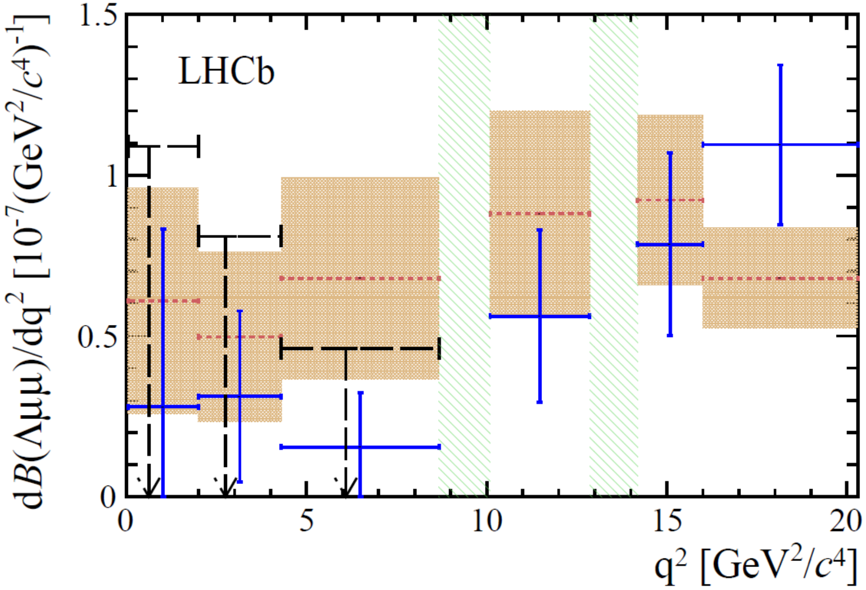


Differential $\mathcal{B}(\Lambda_b^0 \to \Lambda\mu^+\mu^-)$

- Determine the differential branching fraction of $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ in 6 bins of $q^2 \equiv m(\mu^+\mu^-)^2$

arXiv: 1304.0000





- Measure relative branching fraction to $\Lambda_b^0 \to \Lambda J/\psi(\mu^+\mu^-)$
- Significant signal only for $q^2 > m^2_{J/\psi}$
- Good agreement with SM prediction

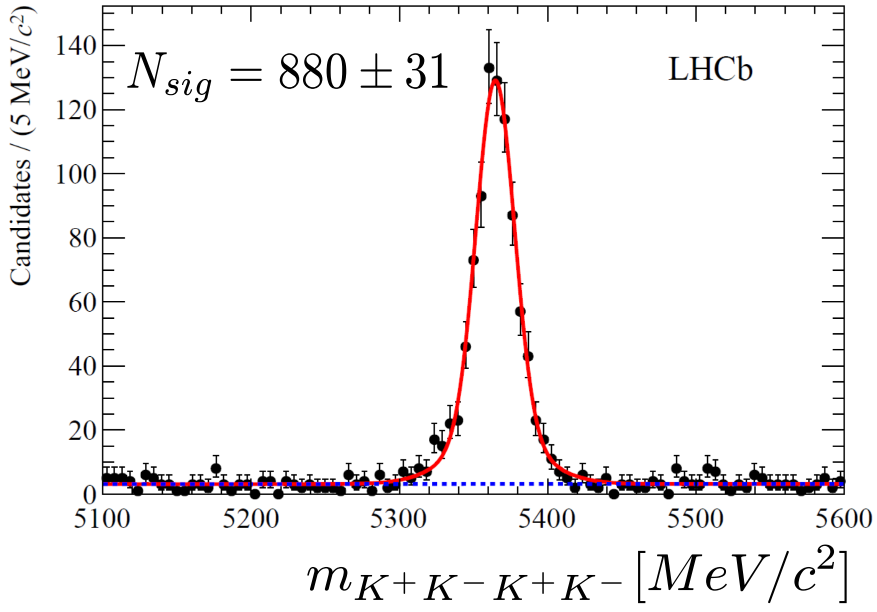
- Total branching fraction

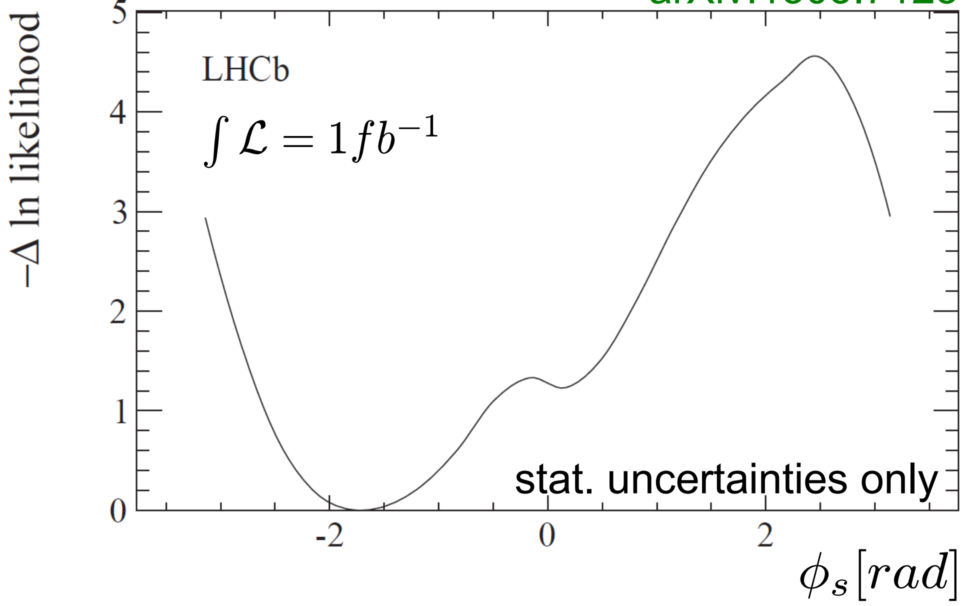
$$\mathcal{B}(\Lambda_b^0 \to \Lambda\mu^+\mu^-) = (0.96 \pm 0.16\,(stat)\ \pm 0.13\,(syst) \pm 0.21\,(norm)) \times 10^{-6}$$

$\phi_s^{s\bar{s}s}$ Measurement in $B_s \to \phi\phi$

- $B_s^0 \to \phi\phi$ proceeds via a gluonics penguin decay $(b \to s\bar{s}s)$ with a small weak phase in SM, $\phi_s^{s\bar{s}s} \approx 0.01$
- Analysis is similar to $B_s^0 \to J\psi\phi$ with Γ_s , $\Delta\Gamma_s$ fixed to values obtained

arXiv:1303.7125



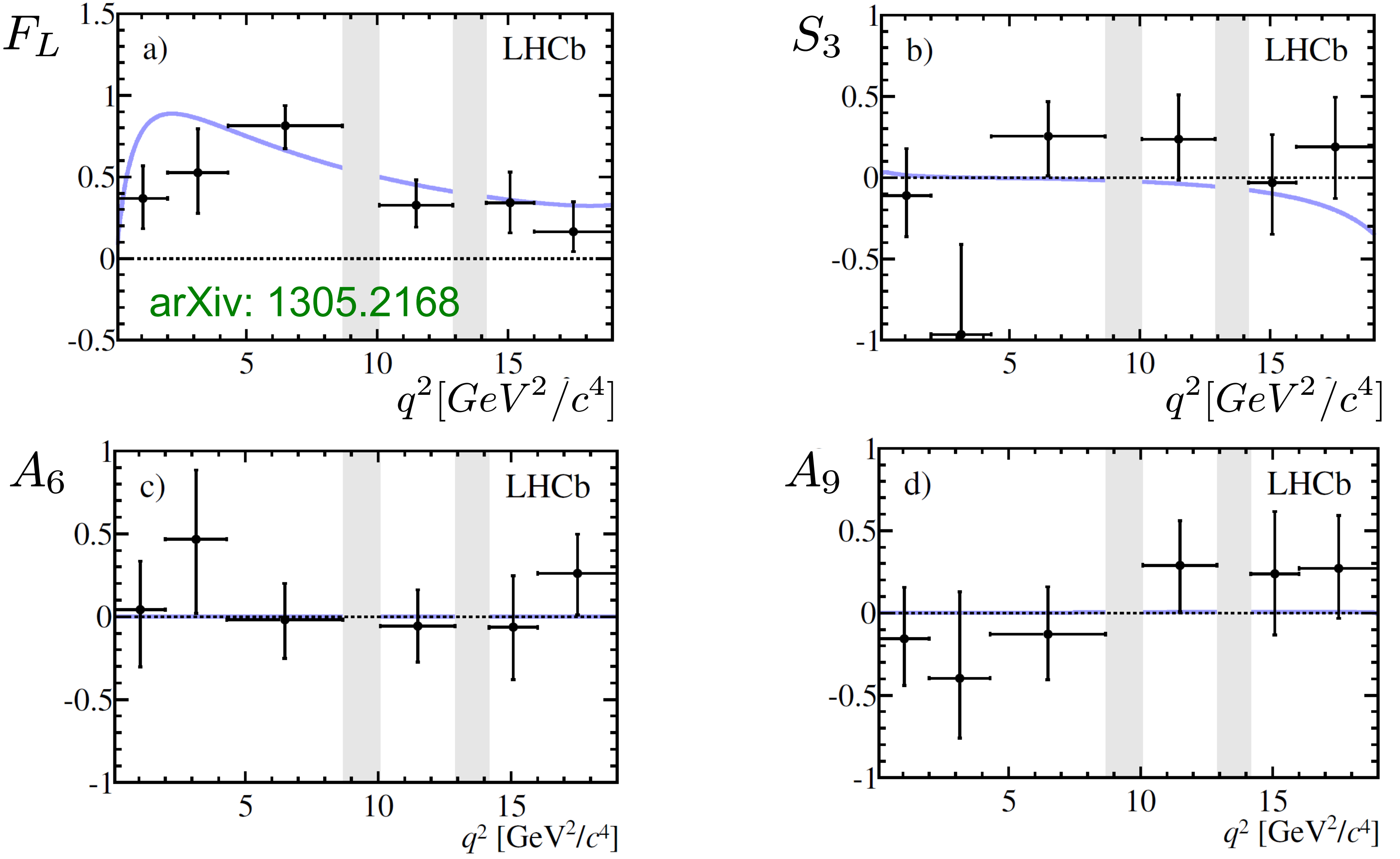


- ϕ_s in $[-2.46, -0.76]\, rad \;@\, 68\%\, C.L.$
sys. uncertainties included

- Compatible with SM prediction

$B_s \to \phi\mu^+\mu^-$ Angular Observables

- Unbinned maximum likelihood fits to the differential decay rate



arXiv: 1305.2168

First measurements, consitent with leading order SM expectation

$B^0_{(s)} \to \mu^+\mu^-$ Decays

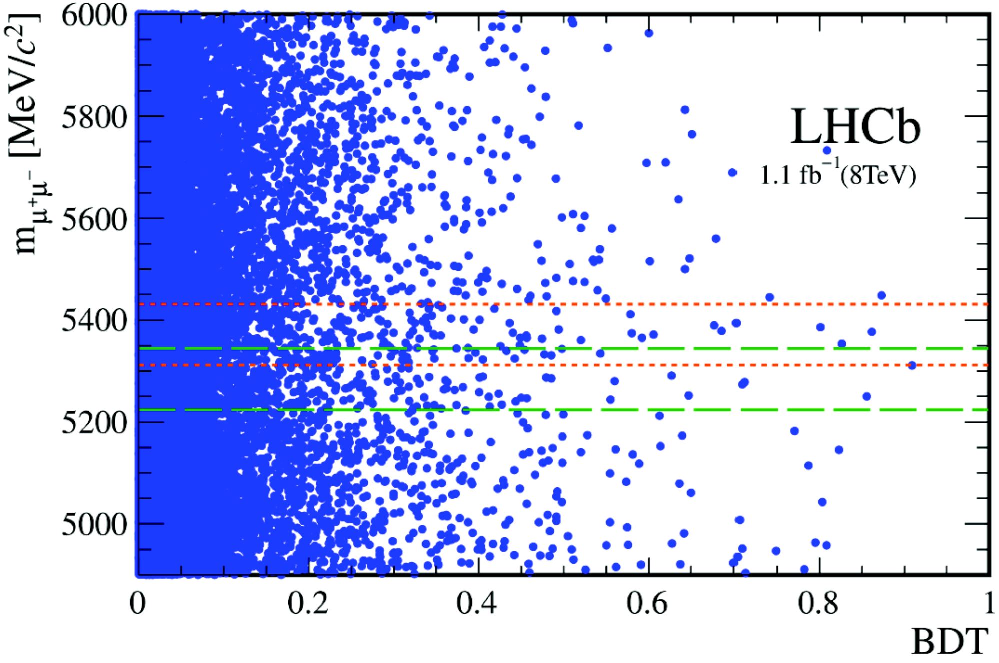
- Small branching ratio predictions for $B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ in SM

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.23 \pm 0.27) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.07 \pm 0.10) \times 10^{-10}$$

$\longrightarrow$ Deviations probe physics beyond SM

- Analysis strategy
  - $\int_{2011} \mathcal{L} = 1.0 fb^{-1} + \int_{2012} \mathcal{L} = 1.1 fb^{-1}$
  - Classification of candidates in 2-D space of $m(\mu^+\mu^-)$ and a BDT
  - Calibrate expectations using control channels
  - Use normalisation channnels
  - Simultaneous unbinned likelihood fit to 15 BDT bins

arXiv:1211.2674

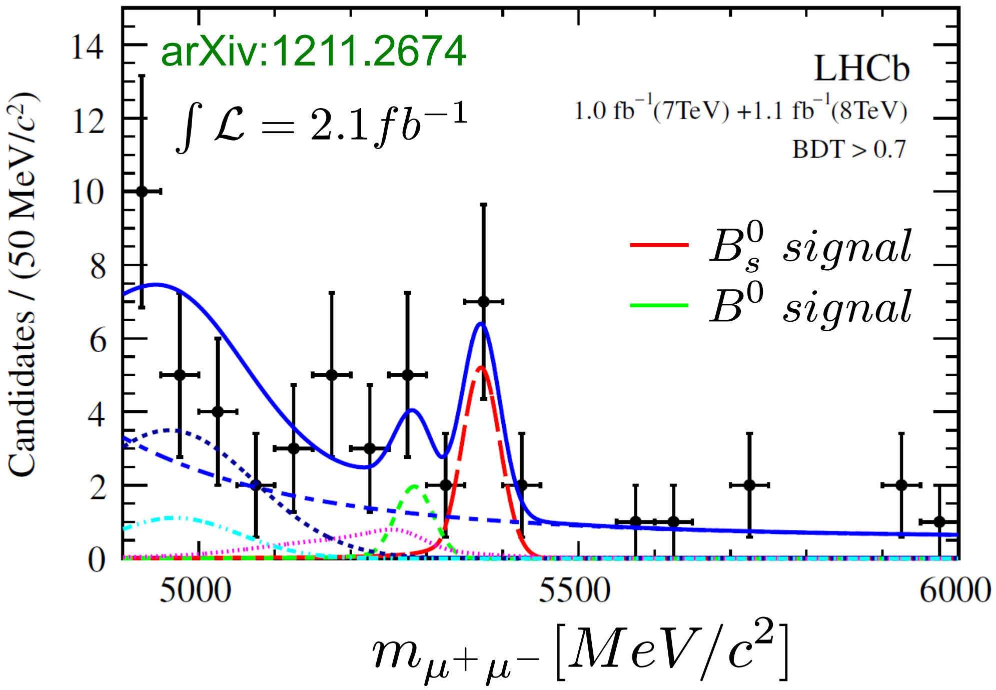


First Evidence for $B_s \to \mu^+\mu^-$

- Observe $3.5\,\sigma$ access of $B_s^0 \to \mu^+\mu^-$ candidates compared to background

  $(p - value\ bck.\ only : 5 \cdot 10^{-4})$

  - $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 3.2^{+1.5}_{-1.2} \times 10^{-9}$
  - The results are consistent with SM expectations



- $B^0 \to \mu^+\mu^-$ candidates are compatible with background expectation
  - $\mathcal{B}(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10}$ @ $95\%\ C.L.$

These measurements superceed previous LHCb results

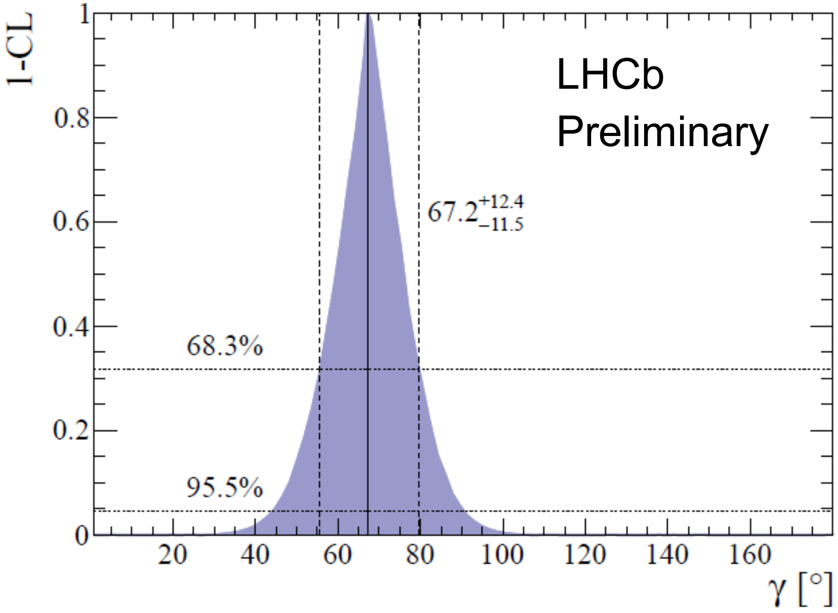
γ Measurement in $B \to DK$ Decays

- Determine γ from combining different methods using LHCb data
  (see arXiv: 1305.2050) $\int \mathcal{L} = 1 fb^{-1}$

$$\gamma = arg(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*})$$

(Two-body GLW/ADS) : B → Dh, D→ hh [**Phys. Lett. B712 (2012) 203**]
(Four-body ADS) : B → Dh, D→ Kπππ [**LHCb-PAPER-2012-055; arXiv:1303.4646**]
(GGSZ) : B → Dh, D→ $K_s$hh [**Phys. Lett. B718 (2012) 43**]

- Preliminary update using 3 fb^{-1} of data for GGSZ LHCB-CONF-2013-006



- Most precise measurement to date
  $\gamma = (67 \pm 12)^\circ \; @ \, 68\% \; CL$