Search for New Physics in Heavy Quark Decays at LHCb

BEACH 2010, Perugia

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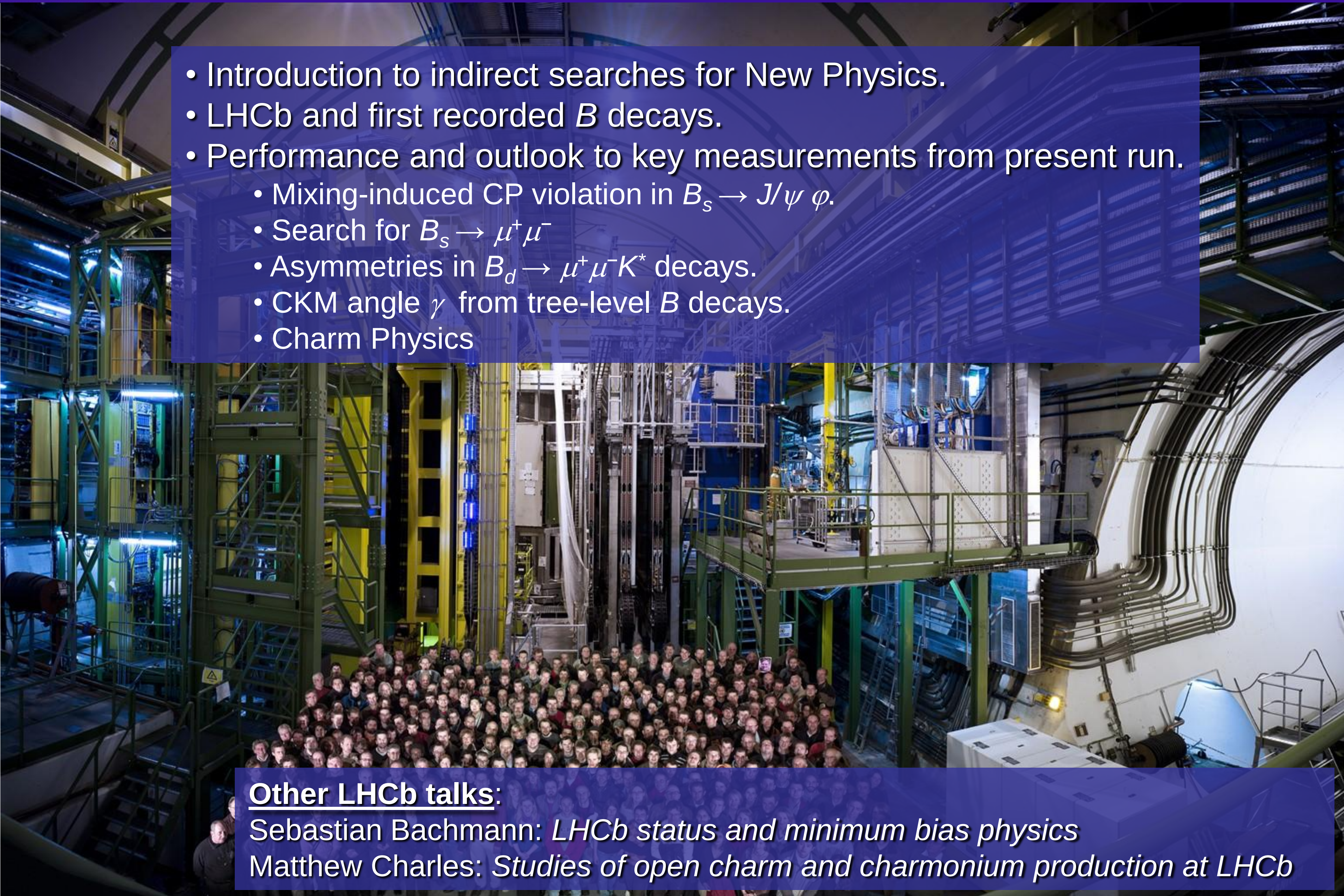
On behalf of the LHCb collaboration

Outline

- Introduction to indirect searches for New Physics.
- LHCb and first recorded *B* decays.
- Performance and outlook to key measurements from present run.
  - Mixing-induced CP violation in $B_s \to J/\psi\ \varphi$.
  - Search for $B_s \to \mu^+\mu^-$
  - Asymmetries in $B_d \to \mu^+\mu^- K^*$ decays.
  - CKM angle γ from tree-level *B* decays.
  - Charm Physics

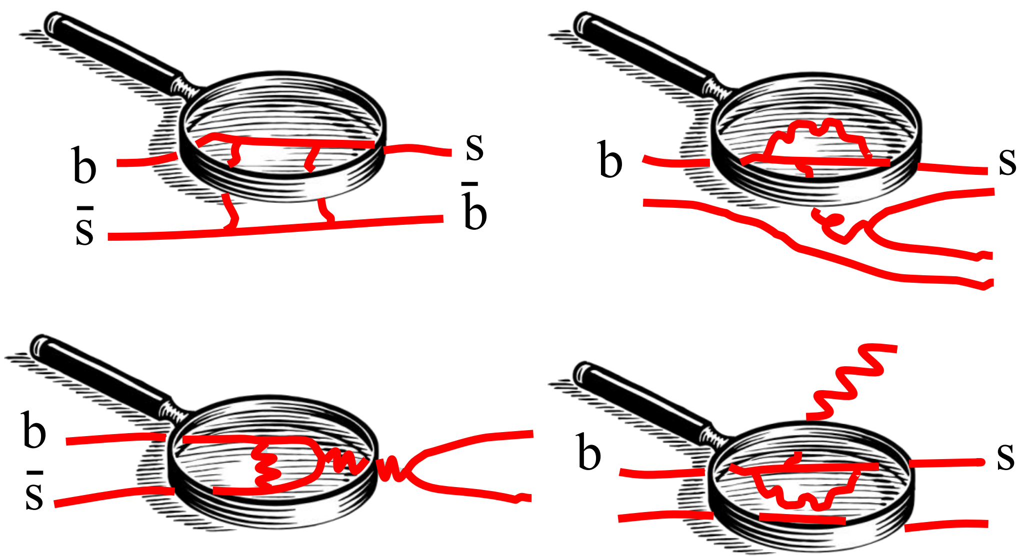


Other LHCb talks:
Sebastian Bachmann: *LHCb status and minimum bias physics*
Matthew Charles: *Studies of open charm and charmonium production at LHCb*

Indirect measurements of New Physics

- New particles can appear as virtual particles in loop and penguin diagrams.
- Indirect searches can have a higher sensitivity to effects from new particles.
  - See NP effects before the direct searches.
  - Indirect measurements can access higher scales.
- Good chance to see NP appear first in loop or penguin diagrams
- Possible to measure the phases of the new couplings
  - Gives access to the flavour structure of NP.

→ Complementary to direct searches.



Search for New Physics

Two approaches for NP searches in heavy flavour decays

1. Transitions involving flavour-changing, neutral currents (FCNC).

- Forbidden at tree level in SM: can be easily modified by New Physics.
  - Especially in $b \rightarrow s$ transitions (not so much constrained by current data).
- Some NP models predict large deviations in FCNC transitions.
  - Add new long-distance operators.
  - Modify short-distance to Wilson coefficients.
- Exploring rare *B* and *D* decays. For instance:
  - Branching ratio of $B_s \rightarrow \mu^+\mu^-$ and $D^0 \rightarrow \mu^+\mu^-$.
  - Helicity structure of $B_d \rightarrow \mu^+\mu^- K^*$ decays.

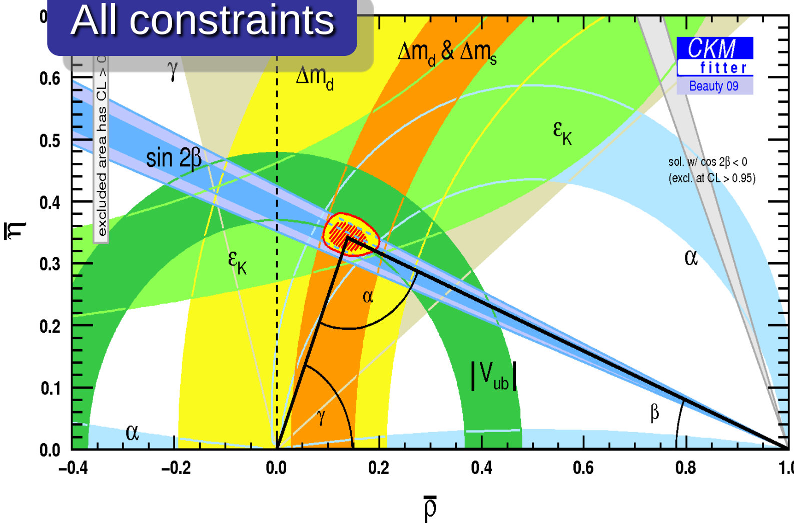
Search for New Physics

Two approaches for NP searches in heavy flavour decays

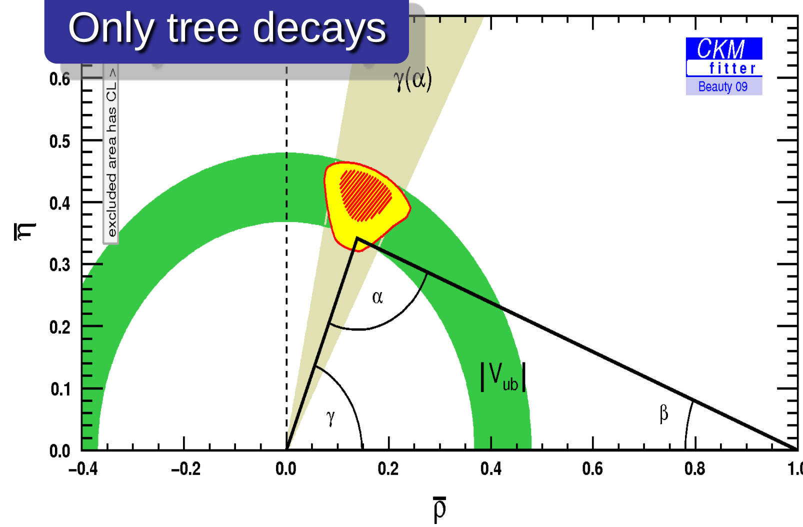
2. Metrology of the CKM matrix

- Improve precision on current constraints
  - Current measurements consistent, but still open to O(10-20%) corrections.
- Compare measurements which may or may not have NP contributions.
  - Explore CKM matrix in many different ways and search for inconsistencies.
- Unitarity triangle not so much constrained from tree decays.
  - Tree decays not affected by New Physics.
  - E.g., a NP free measurement of γ to nail down SM & gain sensitivity to NP.

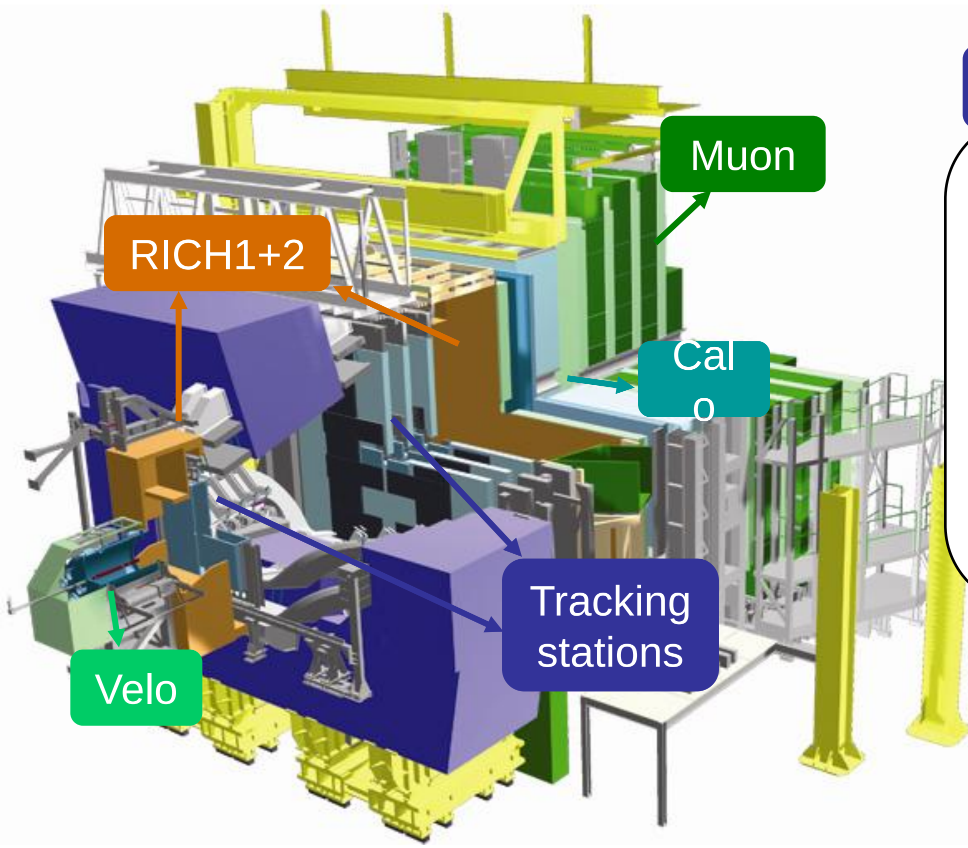
All constraints



Only tree decays



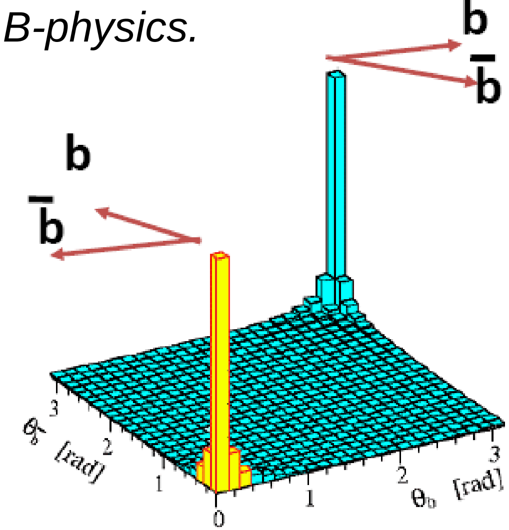
LHCb detector



LHCb made for Heavy Flavour physics

- Good vertex resolution
  - Time-dependent measurements.
  - Suppress background from prompt decays.
- Good particle identification
  - Important for trigger, flavour tagging
  - Suppress background.
- Good momentum resolution
  - Mass resolution of heavy flavours.
  - Suppress background.

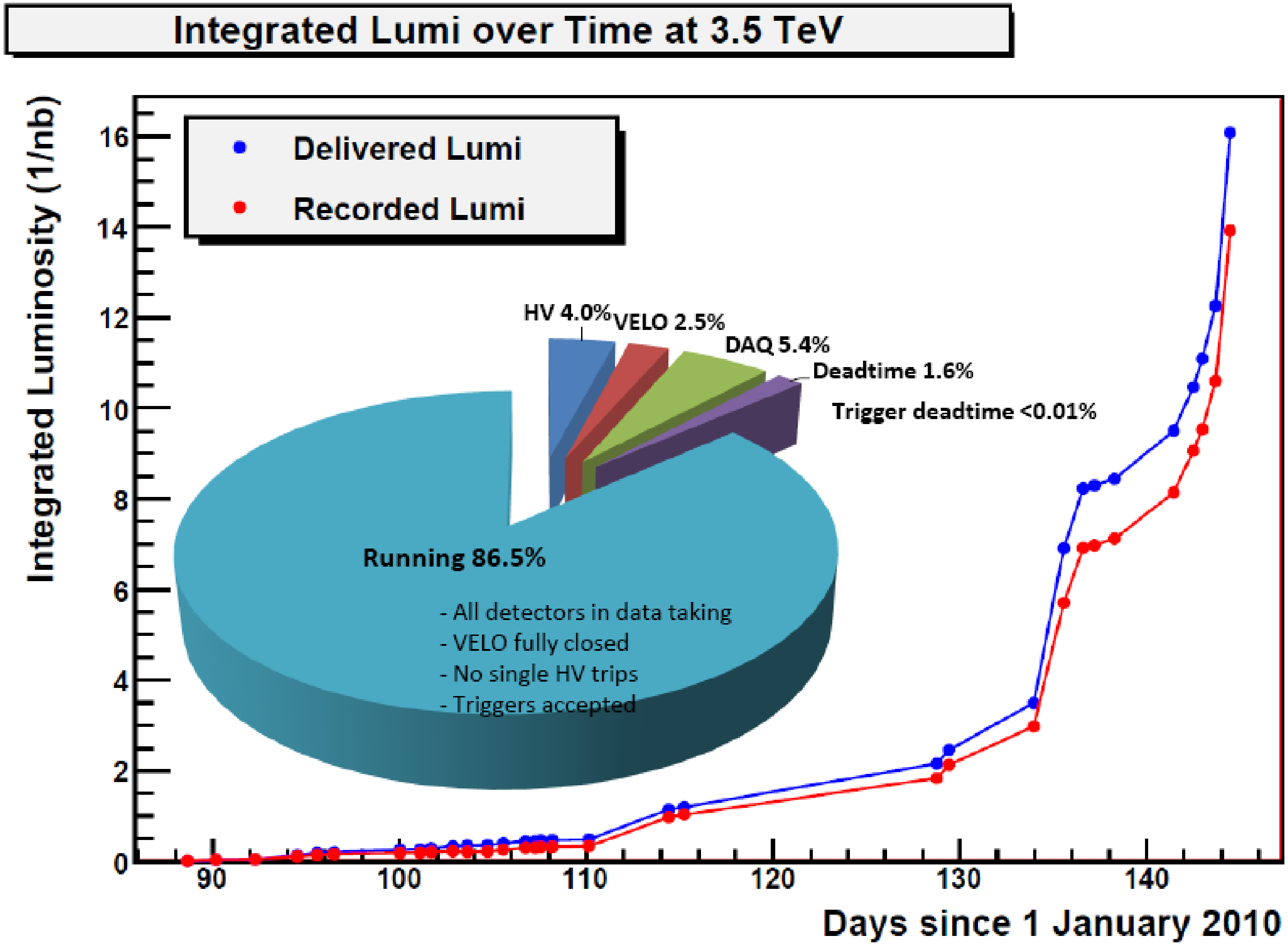
Angular coverage optimised for B-physics.



LHCb can reach its design luminosity very early.

→ See talk of Sebastian Bachmann for a nice overview of LHCb.

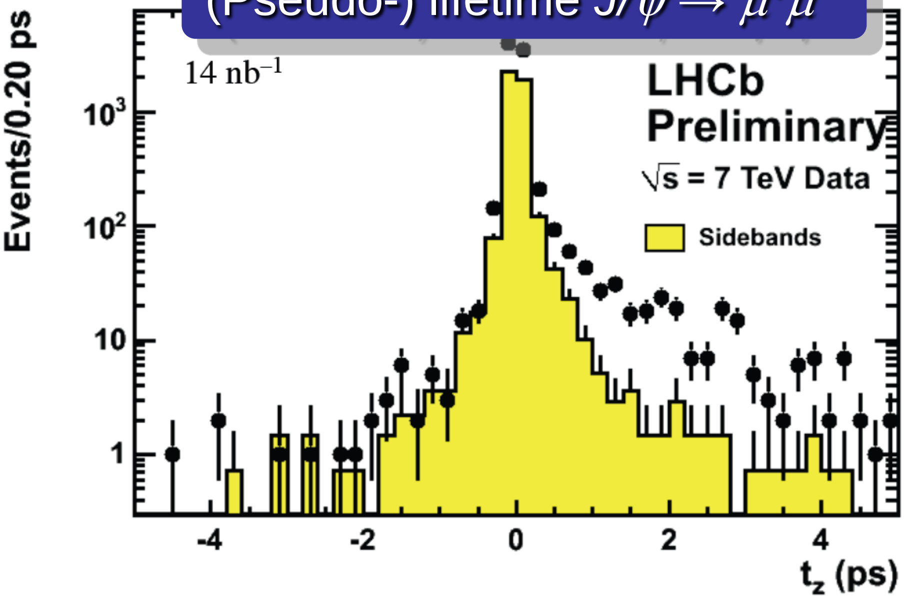
Integrated luminosity



Recorded now:	0.014 pb^{-1}	
Expected this year:	200 pb^{-1}	
Expected end of 2010-11 run:	1000 pb^{-1}	(1 fb^{-1})

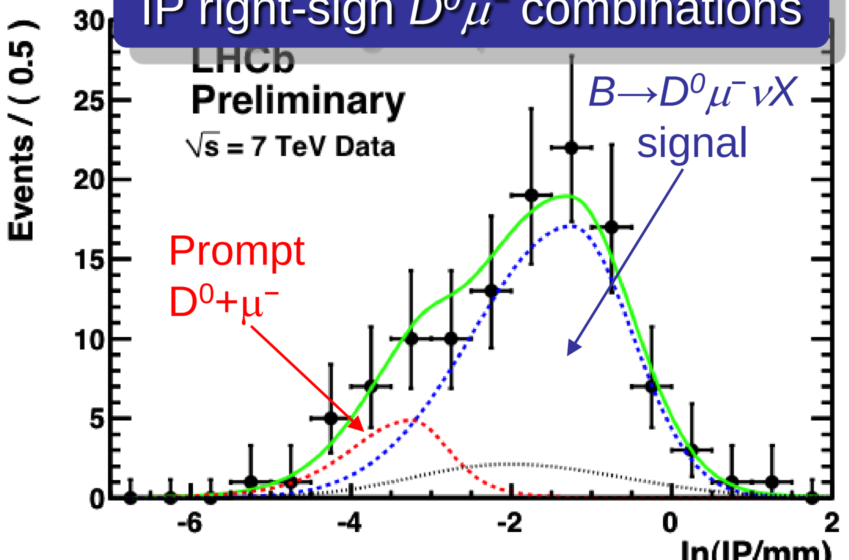
First signs of B hadrons

(Pseudo-) lifetime $J/\psi \rightarrow \mu^+\mu^-$

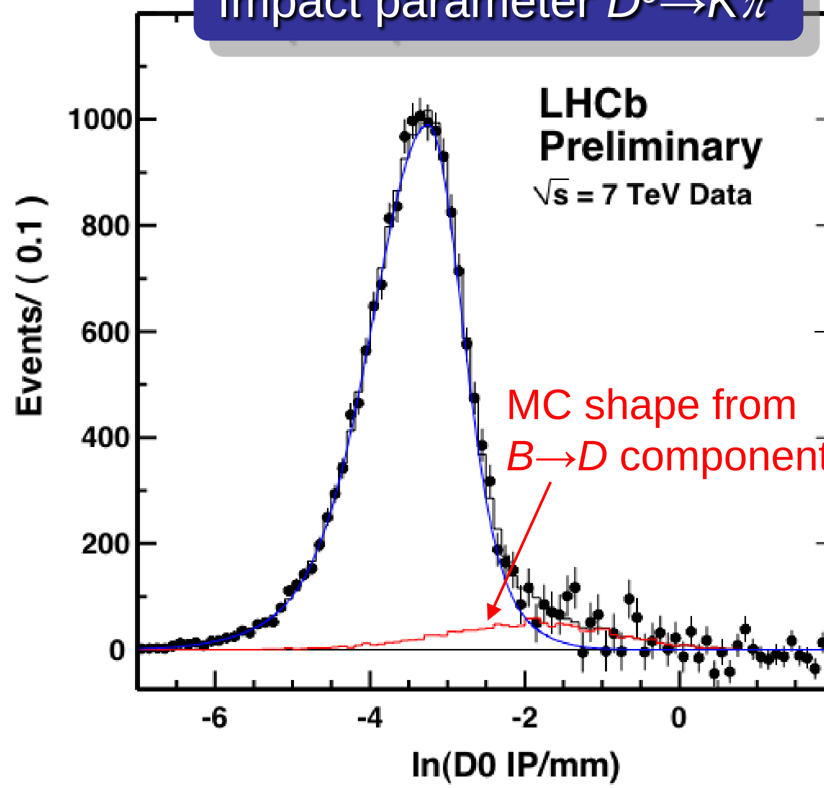


Fingerprints from long-lived B decays

IP right-sign $D^0\mu^-$ combinations

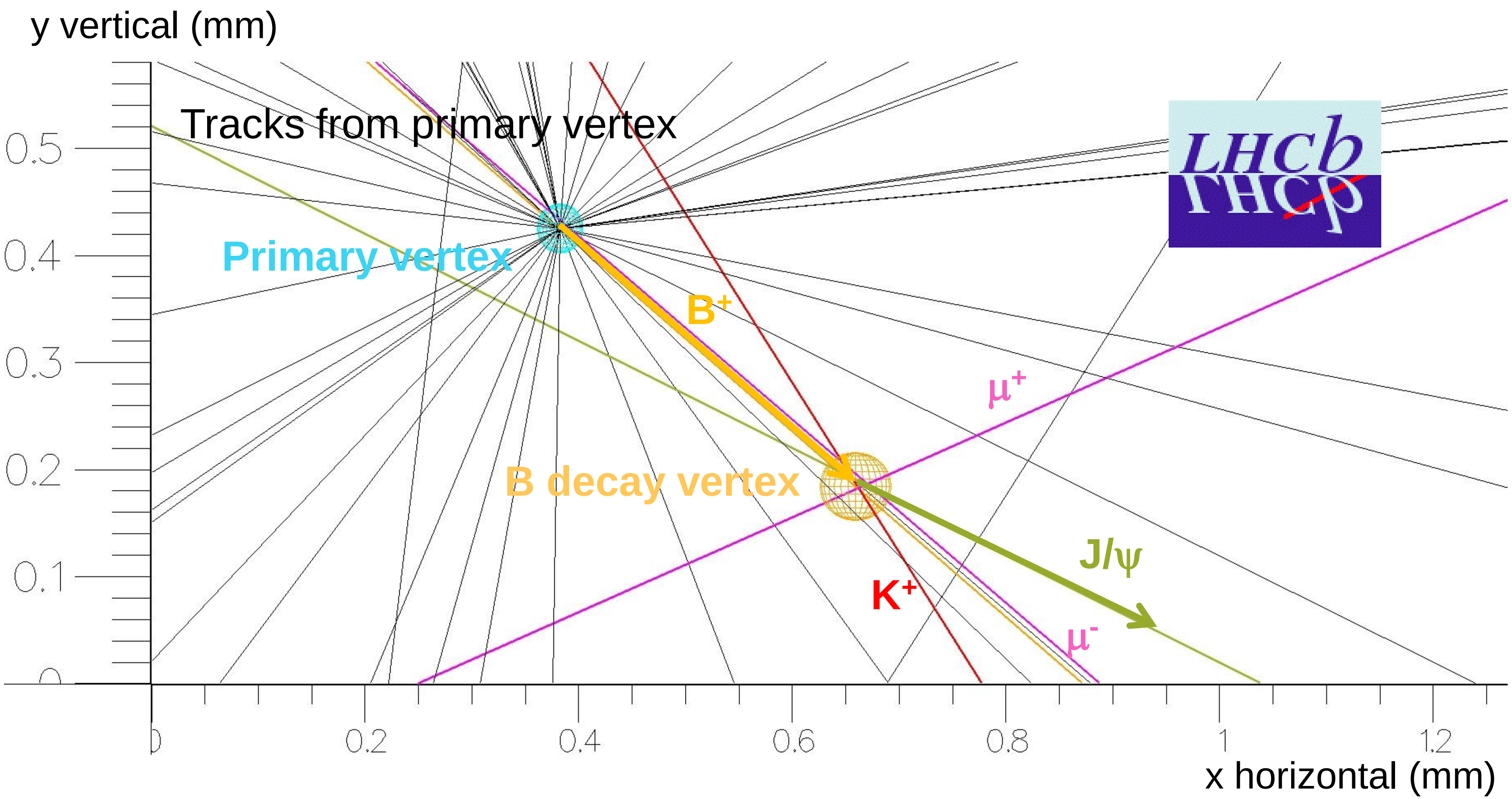


Impact parameter $D^0 \rightarrow K\pi$



See talks from M. Charles and S. Bachmann.

First exclusive *B* candidate

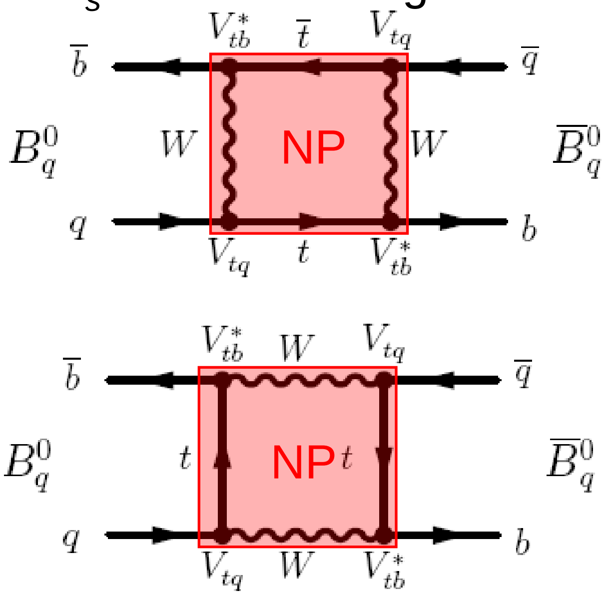


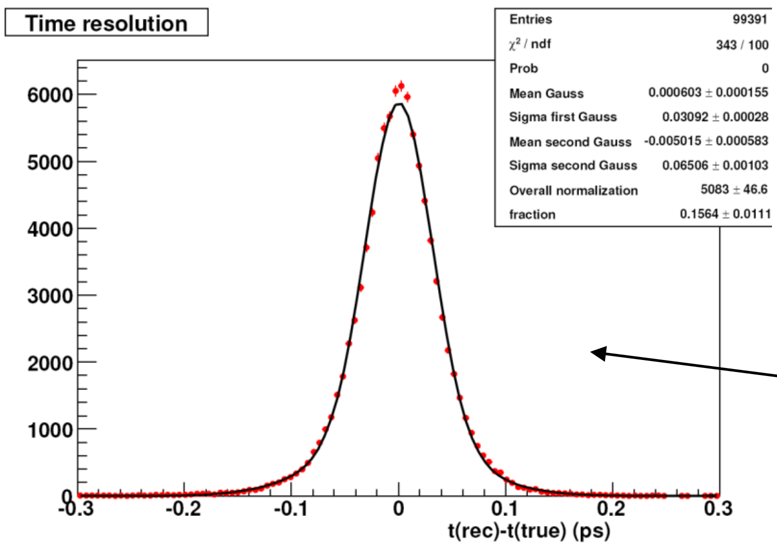
$B^+ \to J/\psi\, K^+$ candidate with good secondary vertex, clearly displaced from primary vertex.

Mixing-induced ~~CP~~ in $B_s \to J/\psi\ \varphi$

- Measures B_s mixing phase through $b \to c\bar{c}s$ decay
  - Mixing phase: $\varphi_s^{SM} = -2\beta_s$
  - Small penguin pollution.
  - B_s counterpart of $B_d \to J/\psi\ K^0$.
- Mixing phase small in SM: $2\beta_s$ = 0.036 0.002
  - New particles in box diagrams can modify measured phase $\varphi_s = \varphi_s^{SM} + \varphi_s^{NP}$

B_s oscillation diagrams



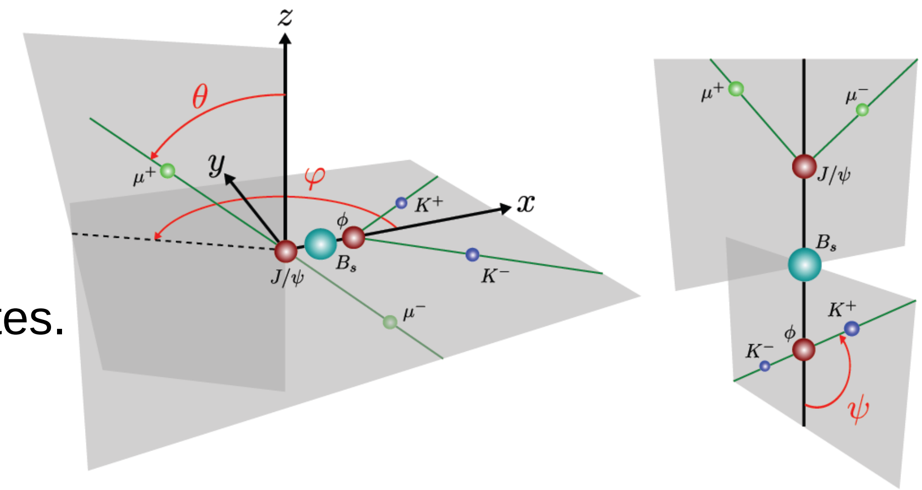


<u>Experimental challenges</u>:

- Requires flavour tagging:
  - Mistag rate: ω~33%, tagging power ε~6%.
- Requires accurate measurement of decay time (to resolve oscillations).
  - Time dependent fit with resolution ~ 40 fs.
- Requires angular analysis
  - See next slide.

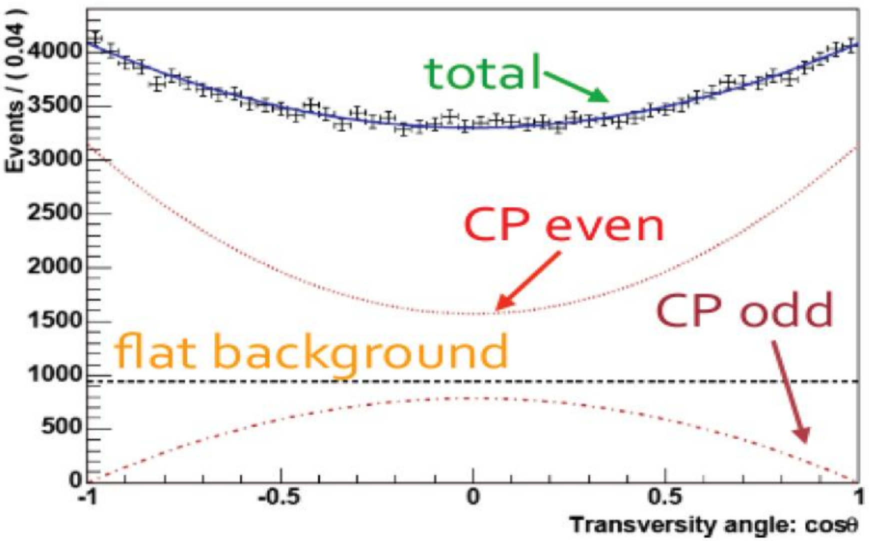
Angular analysis

$P \to VV$ decay: requires angular analysis to disentangle CP-even and CP-odd final states.



Use control channels to check angular acceptance description:

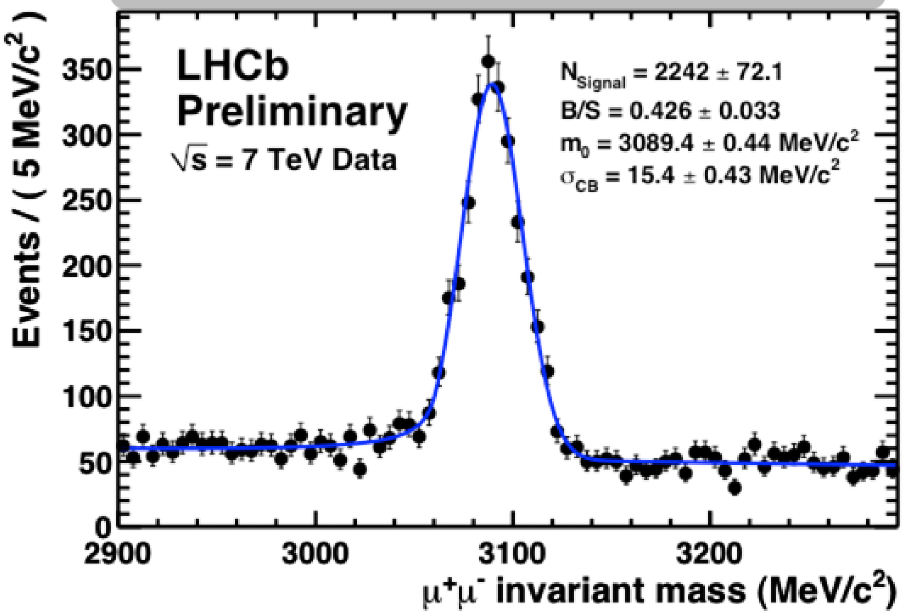
- $B^+ \to J/\psi\, K^+$
- $B \to J/\psi\, K^*$



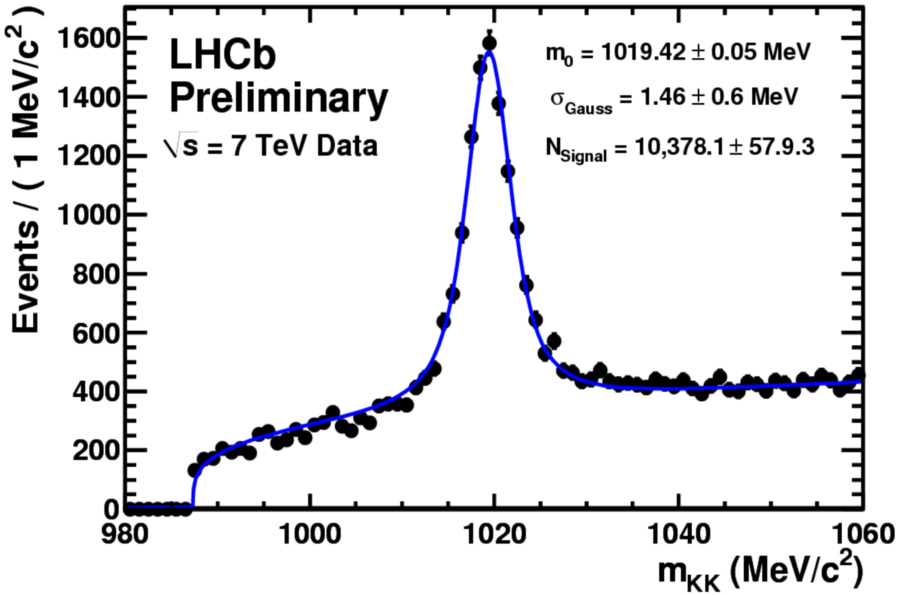
In addition, include pure CP eigenmodes (e.g. $B_s \to J/\psi\, f_0, \eta, \eta'$) as cross-check.
→ No angular analysis needed.

Mixing-induced ~~CP~~ in $B_s \to J/\psi\, \varphi$

$J/\psi \to \mu^+\mu^-$ from real data



$\varphi \to K^+K^-$ from real data



Next step: the first $B_s \to J/\psi\, \varphi$ candidate…

Mixing-induced CP in $B_s \to J/\psi\, \varphi$

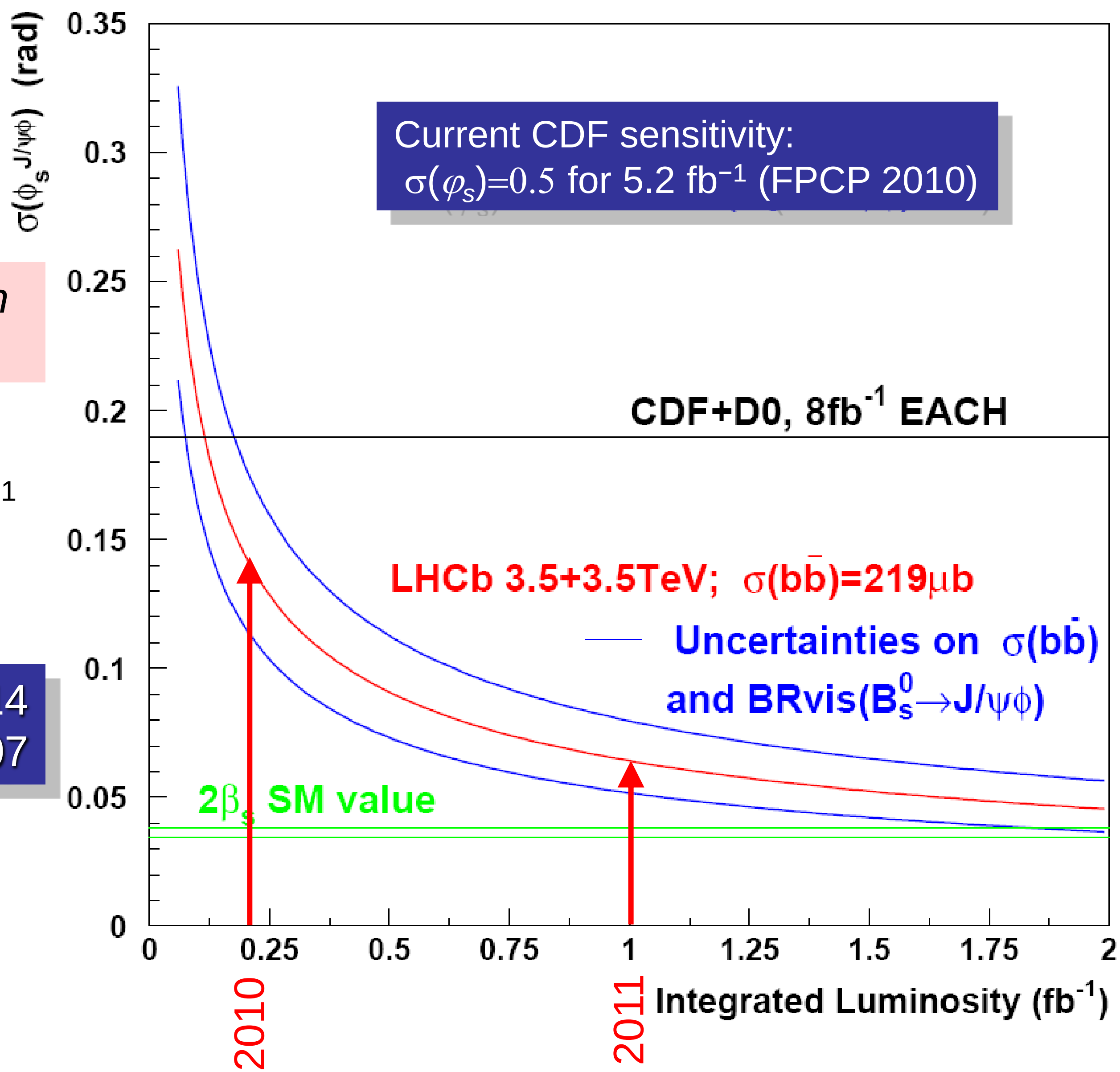
Promising measurement in presence of New Physics.

Expect 50k events in 1 fb^{-1}

LHCb's sensitivity

$\sigma(\varphi_s)$ with 0.2 fb^{-1}	0.14
$\sigma(\varphi_s)$ with 1.0 fb^{-1}	0.07

Note that sensitivity from $B_s \to J/\psi\, f_0(980)$ could be similar, depending on BR.



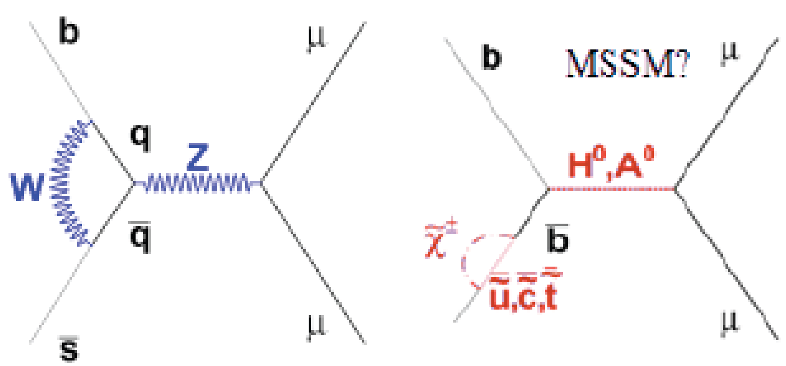
Search for $B_s \rightarrow \mu^+\mu^-$

- Very rare decay. Prediction in SM: BR = (3.35   0.32)x10^{-9} [hep-ph/0604057v5]
- Sensitive to New Physics:
  - E.g. branching ratio in MSSM enhanced by sixth power of tanβ:

$$\mathrm{BR}(B_s \rightarrow \mu^+\mu^-) = 5\times10^{-7}\left(\frac{\tan\beta}{50}\right)^6\left(\frac{300\mathrm{GeV}}{M_A}\right)^4$$

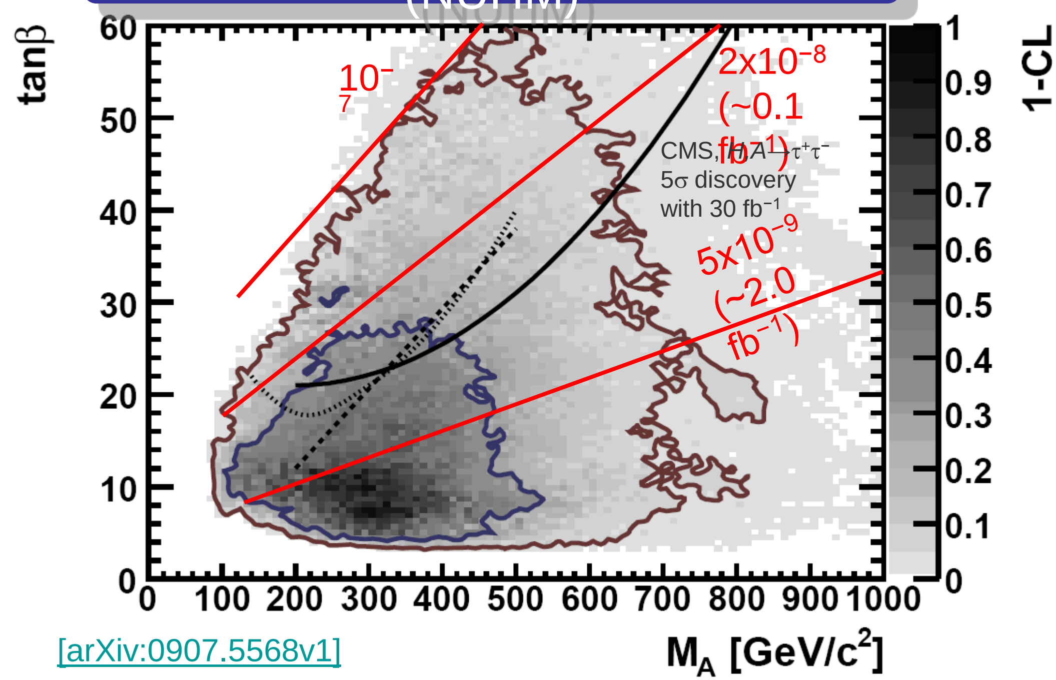
- Present limit from CDF (3.7 fb^{-1}):

  BR < 3.6 x 10^{-8} (90% CL).



The decay $B_s \rightarrow \mu^+\mu^-$ provides sensitive probe for New Physics.

Exclusion regions in MSSM (NUHM)

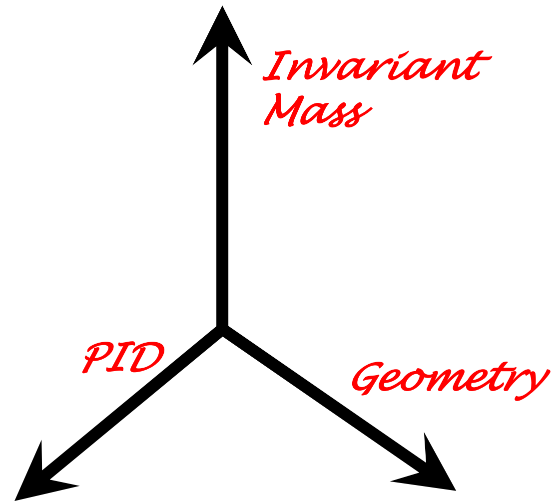


[arXiv:0907.5568v1]

Selection strategy

- Select signal in a 3D-box of
  - Invariant mass
  - Geometrical likelihood
  - PID likelihood

→ Uncorrelated variables with different control samples



→ Invariant mass

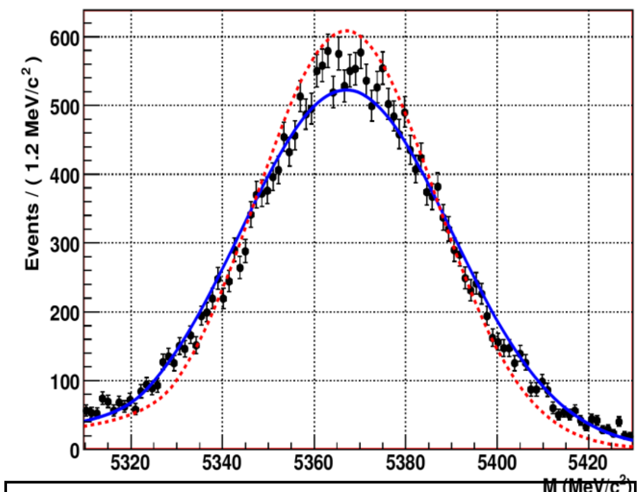
- Detailed studies done with K_s and J/ψ:

	$K_s \to \pi\pi$	$J/\psi \to \mu\mu$
Data	3.47 0.13 MeV	15.4 0.43 MeV
MC	3.31 0.12 MeV	13.12 0.05 MeV

Dominated by opening angle

Dominated by momentum of daughters

- Ultimately, use kinematically similar decays $B_s \to K^+K^-$ (and $K\pi$, $\pi\pi$).
  - B_s mass resolution from MC ~ 20 MeV

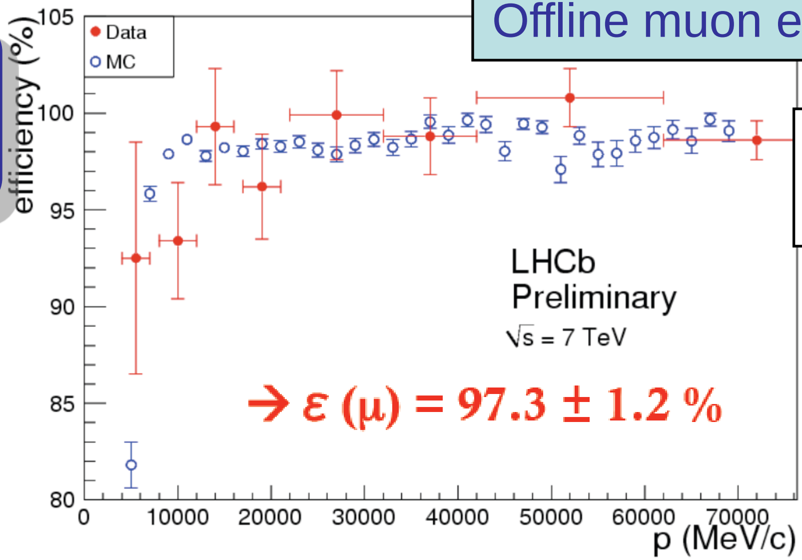


Points: MC $B_s \to \mu^+\mu^-$ mass
Red curve: from $B_s \to K^+K^-$
Blue curve: from $B_s \to K^+K^-$ (with correction for PID)

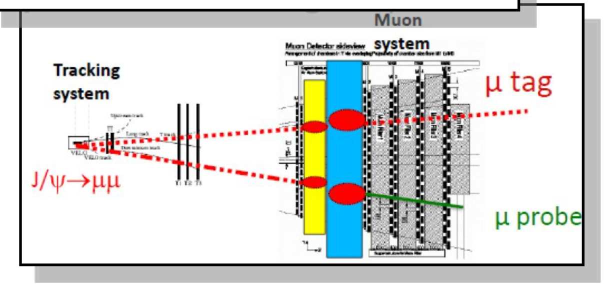
Search for $B_s \to \mu^+\mu^-$

Muon identification

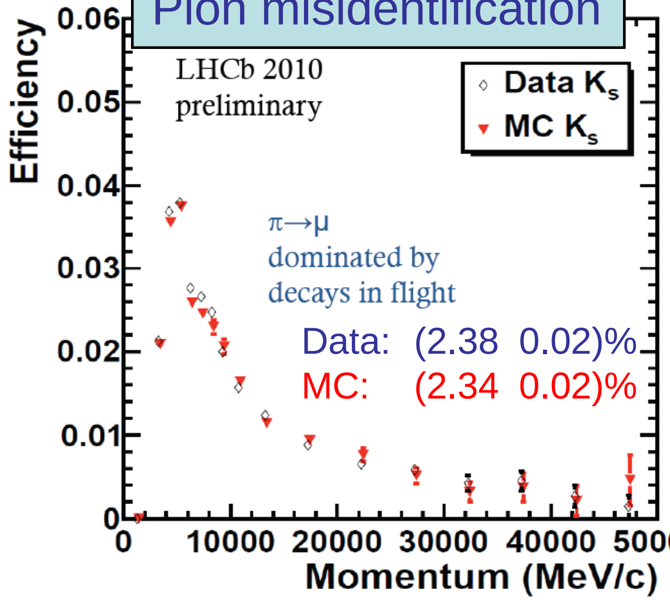
Offline muon efficiency



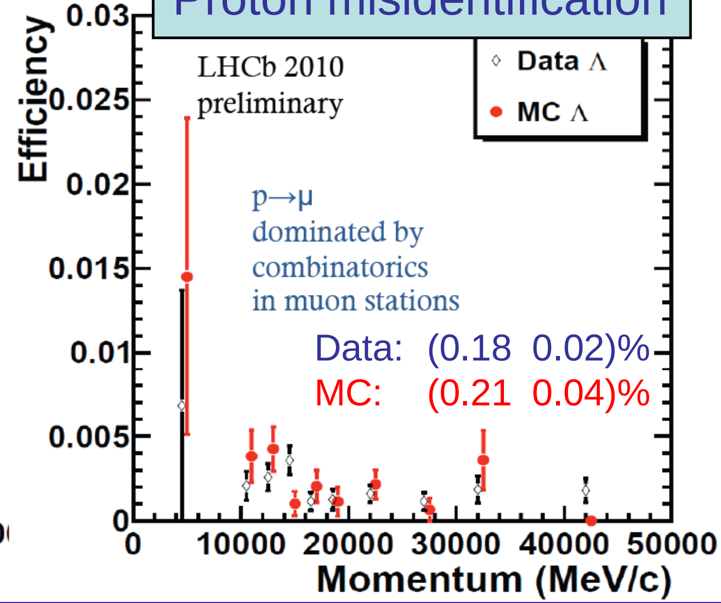
Tag-and-probe method
p>3GeV using J/ψ's



Pion misidentification



Proton misidentification



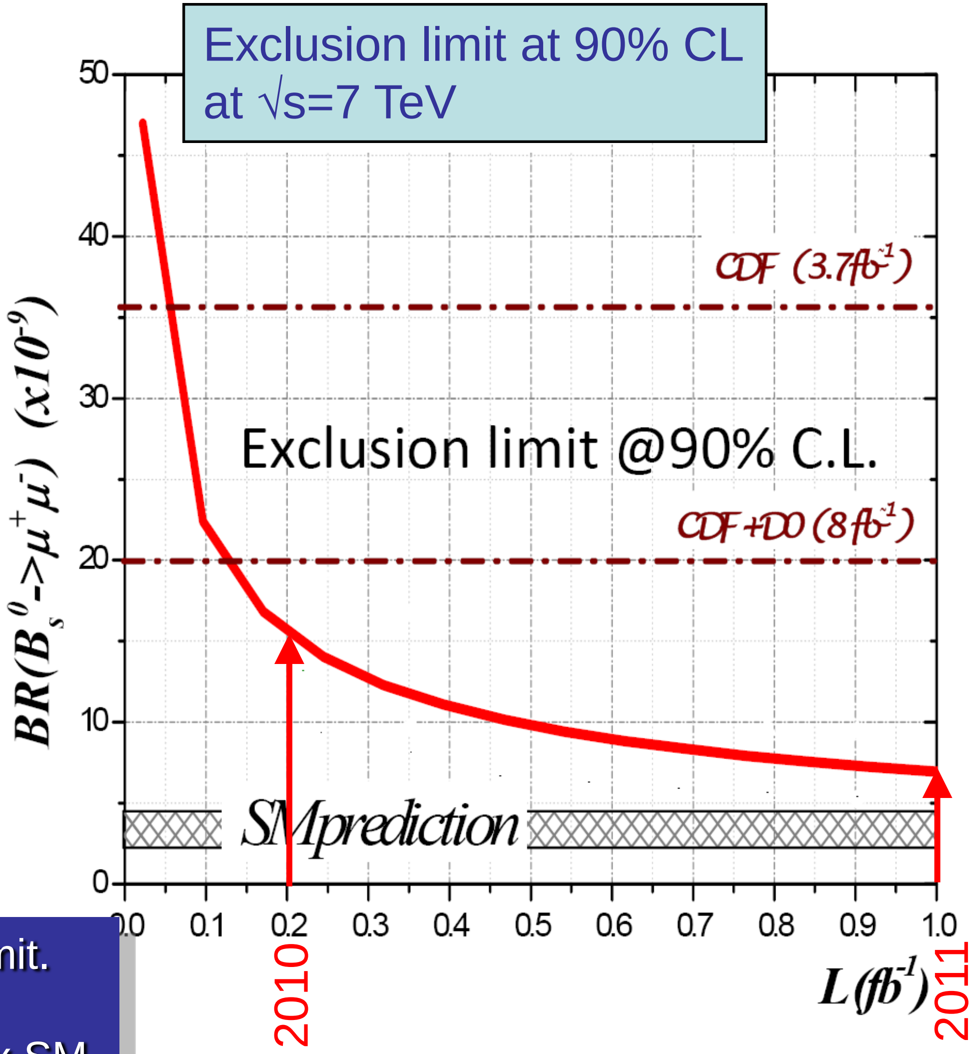
Search for $B_s \to \mu^+\mu^-$

- All studies on data so far indicate that sensitivity from MC is realistic.
- Use known channels to determine BR from event yield
  - $B\to K\pi$ and $B^+\to J/\psi K^+$
- BR($B_s \to \mu^+\mu^-$) can be calculated as:

$$\mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon^{\mathrm{REC}}_{\mathrm{cal}}\epsilon^{\mathrm{SEL|REC}}_{\mathrm{cal}}\epsilon^{\mathrm{TRIG|SEL}}_{\mathrm{cal}}}{\epsilon^{\mathrm{REC}}_{\mathrm{sig}}\epsilon^{\mathrm{SEL|REC}}_{\mathrm{sig}}\epsilon^{\mathrm{TRIG|SEL}}_{\mathrm{sig}}} \times \frac{f_{\mathrm{cal}}}{f_{B^0_s}} \times \frac{N_{B^0_s\to\mu^+\mu^-}}{N_{\mathrm{cal}}}$$

Determine these ratio's from data

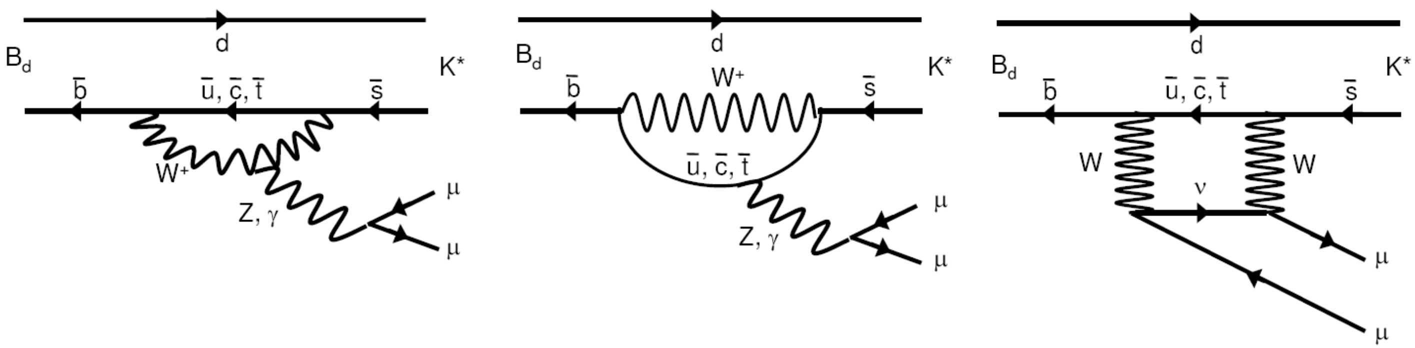
Production ratio known to 13%.
Extract ratio from data using
$B_s\to D_s\pi$ and $B\to D^+K^-$



0.2 fb^{-1} → improve on expected Tevatron limit.
1.0 fb^{-1} → exclude BR down to 7x10^{-9}
or observe 5σ signal if BR = 3.5 x SM.
(Need 10 fb^{-1} at 14 TeV to observe 5σ signal if BR = SM)

Asymmetries in $B_d \to \mu^+\mu^-K^*$

- $B_d \to \mu^+\mu^-K^*$ rare decay in the SM.
  - BR ($B_d \to l^+l^-K^*$) ~ 1.0×10^{-6}
- SM diagrams (can be easily modified in presence of NP):



- Angular distributions contain a lot of information.
  - Many observables sensitive to NP
- For first data focus on forward-backward asymmetry: $A_{FB}(q^2)$.
- Zero crossing point of A_{FB} well predicted in SM (minimize hadronic uncertainties).
  - Measures ratio Wilson coefficients C_9/C_7.
- Sensitive to SUSY, graviton exchanges, extra dimensions…

Asymmetries in $B_d \rightarrow \mu^+\mu^- K^*$

Estimated error on A_{FB}: in most sensitive bin (1−6 GeV^2):

0.1 fb^{-1}: $\sigma(A_{FB})$=0.20

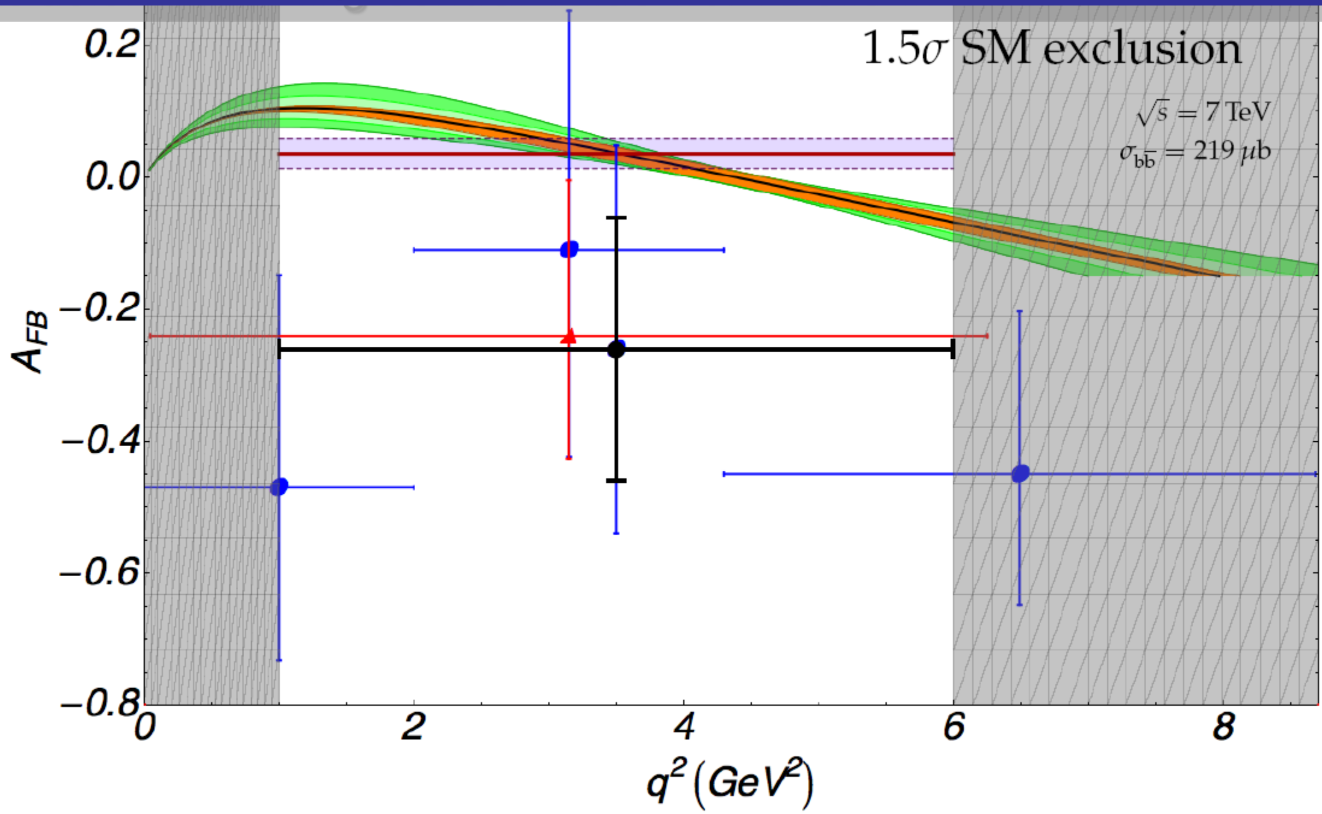
SM exclusion assuming central value from Belle in most sensitive bin

SM prediction

Belle

BaBar

LHCb (projection) at 0.1 fb^{-1}



140 events expected

Asymmetries in $B_d \to \mu^+\mu^- K^*$

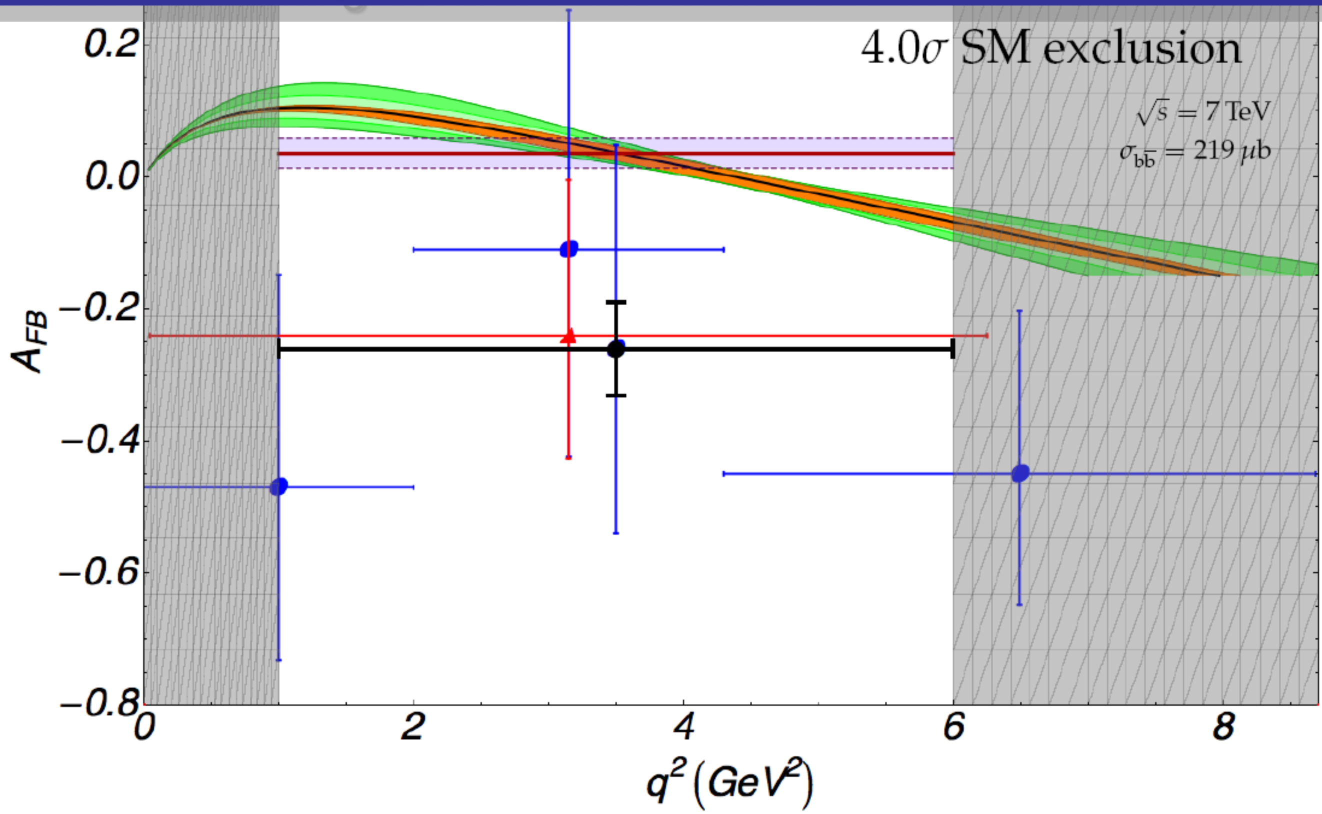
Estimated error on A_{FB}: in most sensitive bin (1−6 GeV^2):

0.1 fb^{-1}: $\sigma(A_{FB})=0.20$

0.3 fb^{-1}: $\sigma(A_{FB})=0.12$

1.0 fb^{-1}: $\sigma(A_{FB})=0.07$ (end of 2011)

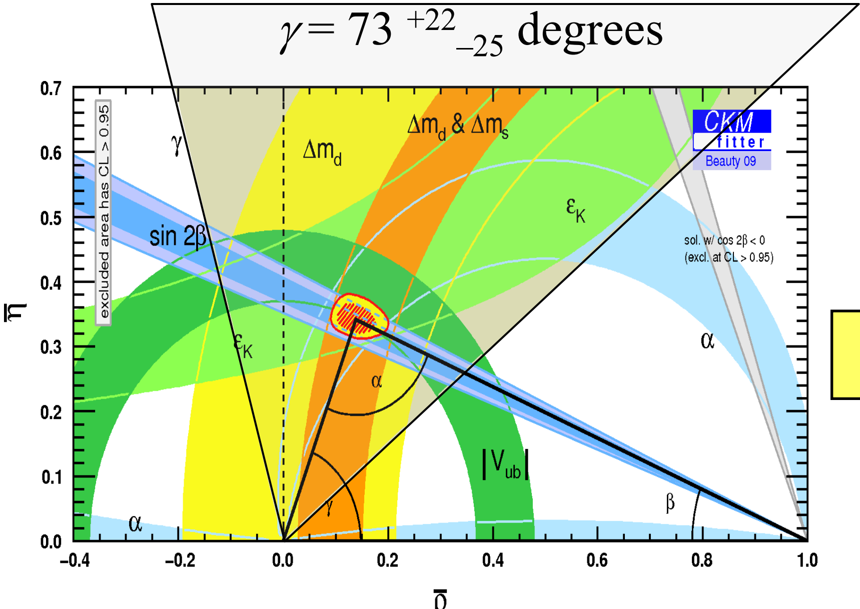
SM exclusion assuming central value from Belle in most sensitive bin



SM prediction
Belle
BaBar
LHCb (projection) at 1.0 fb^{-1}

1400 events expected

CKM angle γ from tree B decays



γ is the least well-known CKM angle

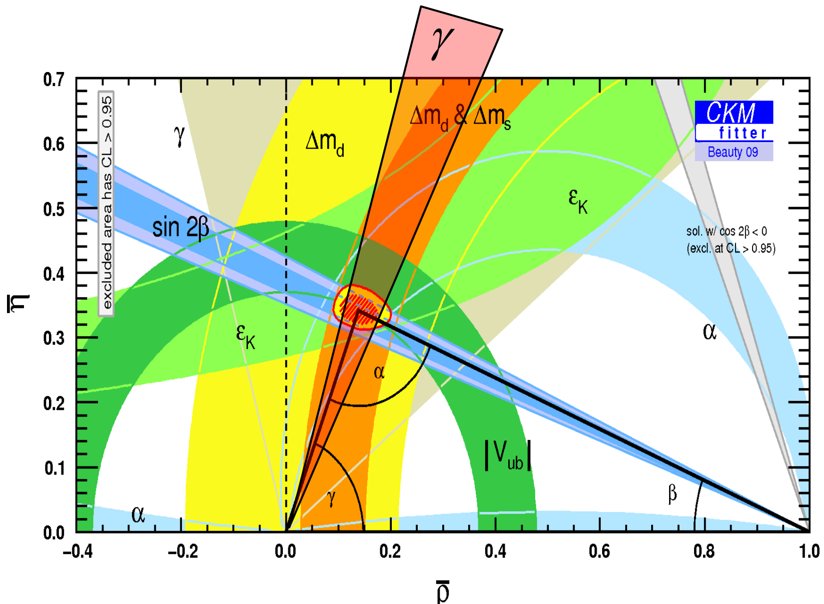
<u>Current experimental status</u>:
- From direct measurements with $B \to DK$ decays: $\gamma = (73^{+22}_{-25})$ ([BaBar] and [Belle])
- From SM fit using only indirect measure-ments: $\gamma = (67.7^{+4.5}_{-3.7})$ [CKMfitter Beauty09]

- Diagrams with $b \to c$ and $b \to u$ transitions → sensitive to γ.
- Use only tree diagrams to allow clean (NP free) extraction of γ.

❑ $B^{+/0} \to D^0 K^{+/*}$
- Measures γ directly through interference between B and subsequent D decay.
- Counting experiment. Measure relative decay rates.
  - ADS+GLW method ($D^0 \to K\pi, KK, \pi\pi, K\pi\pi\pi$)
  - GGSZ (Dalitz) method ($D^0 \to K_s\pi\pi$)

❑ $B_s \to D_s K$
- Measures γ-$2\beta_s$ through interference between mixing and decay.
  - Mixing phase $2\beta_s$ from $B_s \to J/\psi\, \varphi$
- Golden mode, but requires flavour tagging and time-dependent analysis.

CKM angle γ from tree B decays



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❑ $B^{+/0} \rightarrow D^0 K^{+/*}$

- Measures γ directly through interference between B and subsequent D decay.
- Counting experiment. Measure relative decay rates.
  - ADS+GL
  - GGSZ (

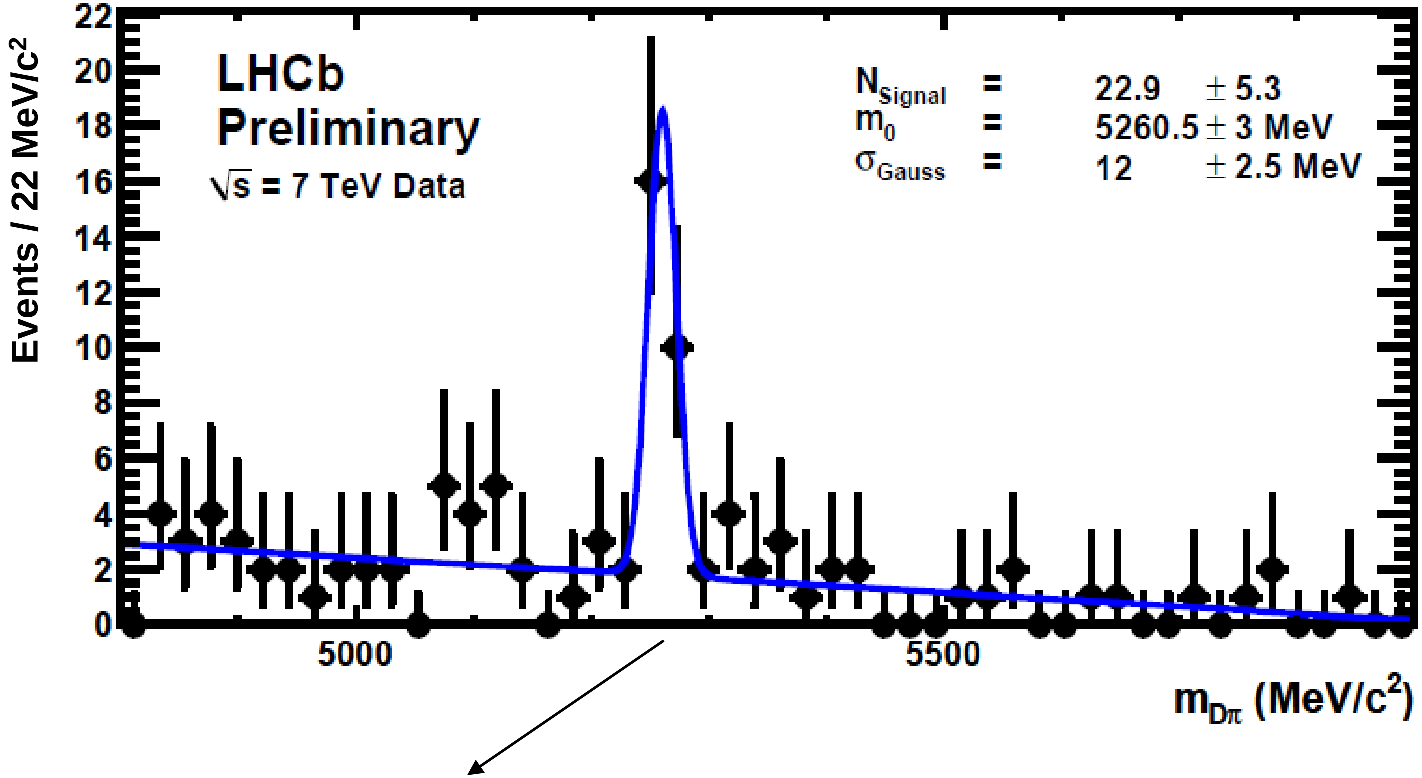
Combined sensitivity ~7° for 1 fb^{-1}.

❑ $B_s \rightarrow D_s K$

- Measures γ-$2\beta_s$ through interference between mixing and decay.
  - Mixing phase $2\beta_s$ from $B_s \rightarrow J/\psi\,\varphi$
- Golden mode, but requires flavour tagging and time-dependent analysis.

CKM angle γ from tree B decays

First two channels of the $B \to DX$ family observed.



Signal by combining
$B^0 \to D^+ \pi^-$ and $B^+ \to D^0 \pi^+$

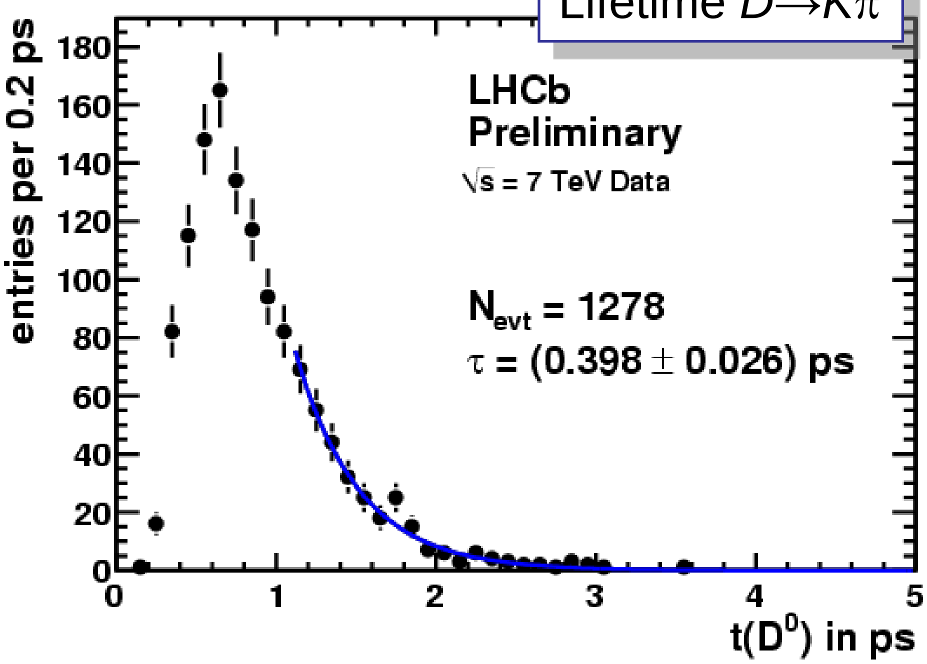
<u>Expect soon</u>

- $B_s \to D_s \pi^-$
- $B \to DK$ (Cabibbo favoured)

LHCb has excellent potential for charm physics

- Dedicated HLT trigger line for $D^{*+} \to D^0(hh')\pi^+$
  - Yield of O(10^8) events per fb^{-1}
  - Flavour tag from charge of pion.
- D^0 time resolution ~0.040 ps (from MC).

Lifetime $D \to K\pi$

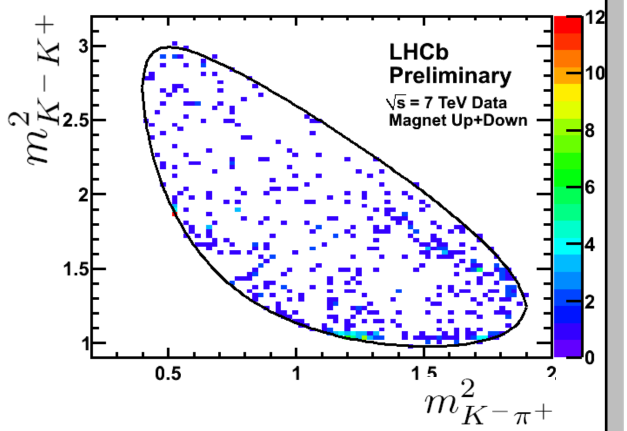


→ See talk of Matthew Charles on open charm and charmonium in LHCb

Charming opportunities in 2010-11 run

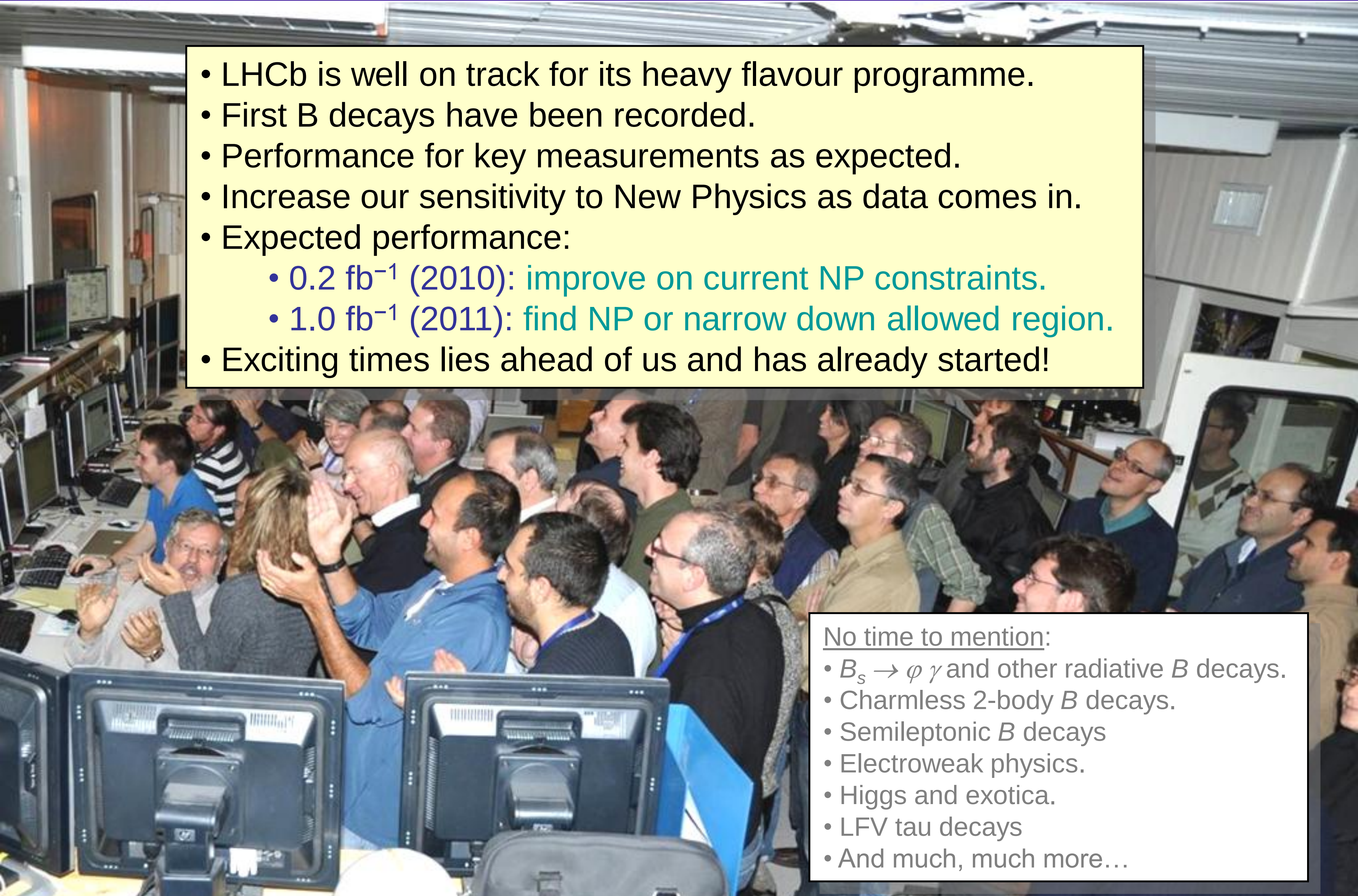
- Mixing parameters and possible CP violation effects.
  - CP violation would indicate New Physics.
  - Lifetime ratio CP mixed and CP even decays (y_{CP}).
    - Expect 17x10^{6} ($D \rightarrow K\pi$; CP mixed) and 1.3x10^{6} ($D \rightarrow KK$; CP even) in 0.1 fb^{-1}.
  - Measurement of oscillation in wrong sign $D \rightarrow K\pi$.
    - Expect 60x10^{3} in 0.1 fb^{-1}

- Direct CPV in single-Cabibbo-suppressed decays.
  - Dalitz analysis with $D^{+} \rightarrow K^{+}K^{-}\pi^{+}$
    - Model independent
    - Not sensitive to production asymmetries.
    - Expect several millions of events in 0.1 fb^{-1}.



- Search for rare decay of $D^{0} \rightarrow \mu^{+}\mu^{-}$.
  - Highly suppressed in SM: BR~3x10^{-13}
  - Can be significantly enhanced by NP.
  - Current experimental limit BR < 1.4x10^{-7} @ 90% CL [Belle]
  - Similar analysis as $B_{s} \rightarrow \mu^{+}\mu^{-}$
  - Expected limit LHCb for 0.1 fb^{-1}: BR < 4x10^{-8} @ 90% CL.

Conclusion



- LHCb is well on track for its heavy flavour programme.
- First B decays have been recorded.
- Performance for key measurements as expected.
- Increase our sensitivity to New Physics as data comes in.
- Expected performance:
    - 0.2 fb^{-1} (2010): improve on current NP constraints.
    - 1.0 fb^{-1} (2011): find NP or narrow down allowed region.
- Exciting times lies ahead of us and has already started!

No time to mention:

- $B_s \to \varphi\, \gamma$ and other radiative *B* decays.
- Charmless 2-body *B* decays.
- Semileptonic *B* decays
- Electroweak physics.
- Higgs and exotica.
- LFV tau decays
- And much, much more…