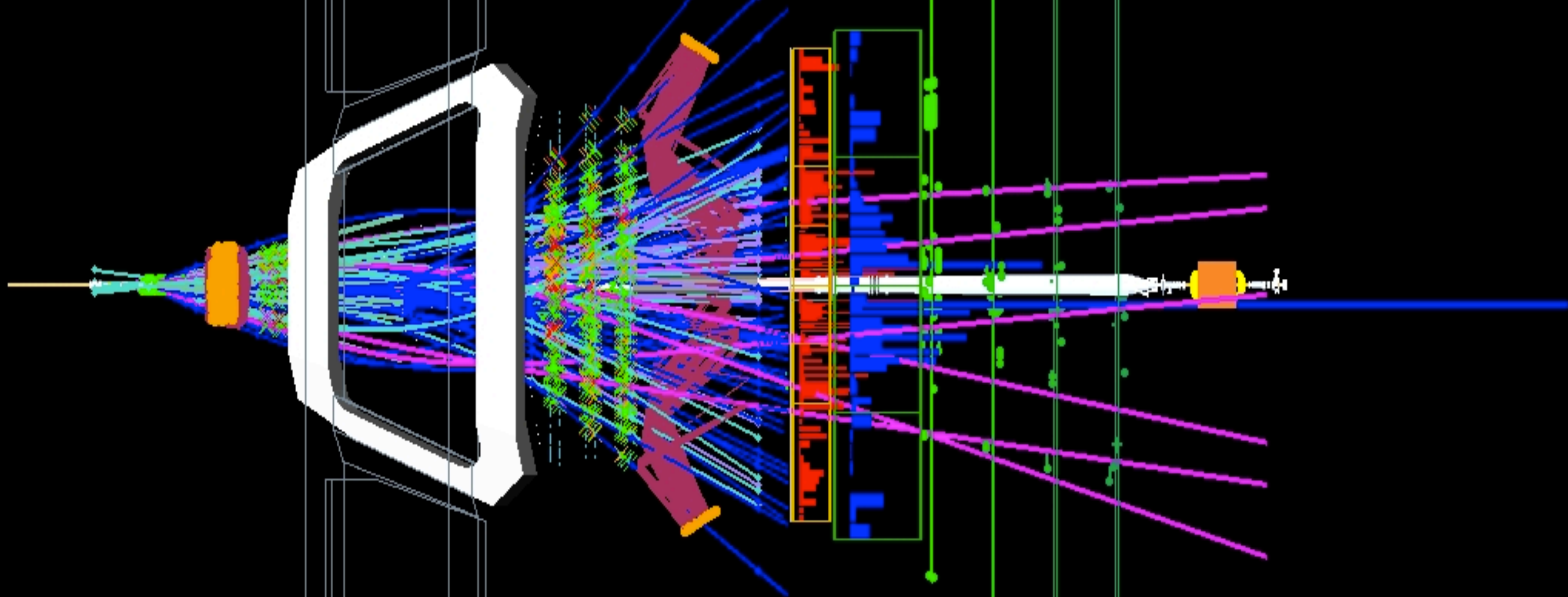
Search for New Physics signals with the LHCb detector at the LHC

Gaia Lanfranchi [INFN-Frascati]

On behalf of the LHCb Collaboration



Centre de Physique des Particules de Marseille

- March 21th , 2011 -

Outline

- Introduction:

  - Flavour physics in the LHC era as a window for New Physics

  - Intriguing anomalies in the Standard Model picture

- LHC: a heavy quarks factory
- The LHCb experiment:

  key experimental ingredients for heavy flavour physics measurements: status of the art

- First results from LHCb from 2010 run and prospects for the 2011 run

Flavour Physics in the LHC era

- Flavour physics has been so far a powerful probe to test the Standard Model structure.

- However the Standard Model cannot be the ultimate theory:
  - it does not explain the hierarchy problem, the dark matter problem, the baryon asymmetry, the mass pattern and mixing angles of quarks and leptons and it does not account for gravitational interactions. **In particular the baryon asymmetry and the neutrino mass cannot be explained in the SM and are of a flavour physics nature.**

- The SM is likely the low-energy ($\sim M_W$) limit of a more fundamental theory that involves new particles, symmetries and degrees of freedom at higher energy scale.

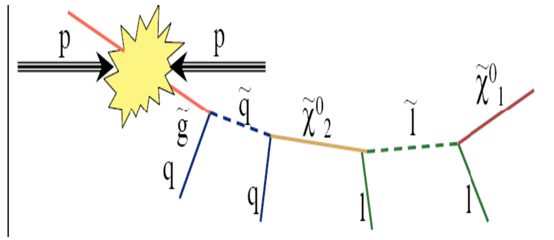
- Therefore the two key questions of particle physics today are:
  1) which is the energy scale of new physics?
  2) which is the symmetry structure of the new degrees of freedom?

Flavour Physics in the LHC era

Two complementary ways to answer these two questions:

1) Direct searches in high-p_T physics:

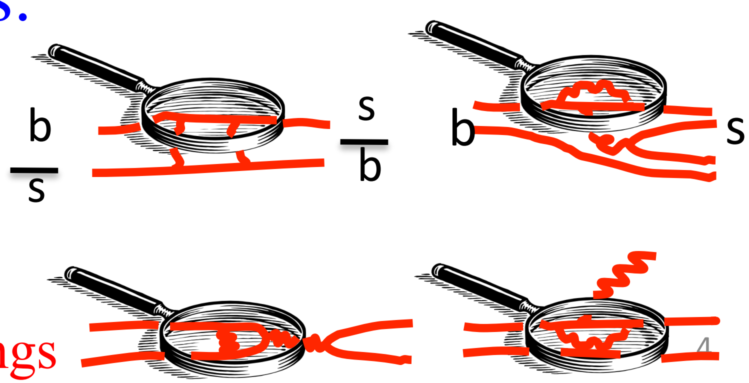
→ look for real particles with specific signatures (mostly ATLAS/CMS domain)



2) Indirect searches in flavour physics:

→ look for virtual particles in loop processes leading to observable deviations from SM

- can access higher energy scale
  [see the effect earlier]
- can study the flavour structure of new couplings
  [phases & amplitudes]



Flavour Physics in the LHC era

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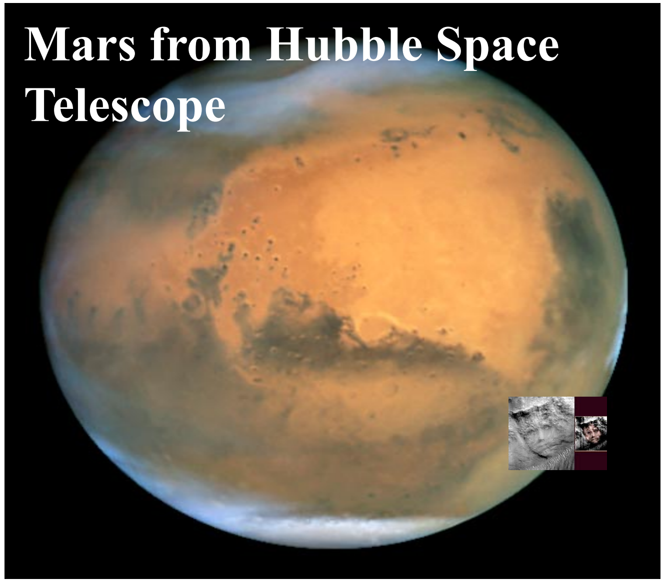
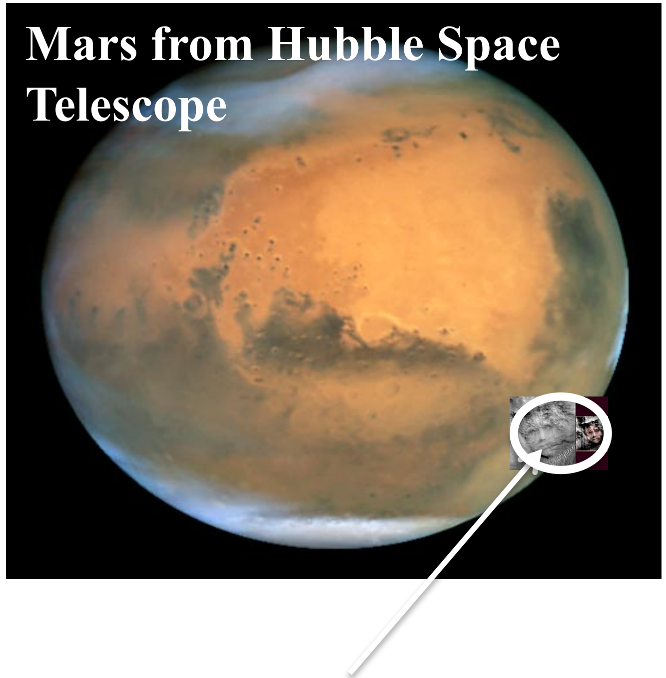
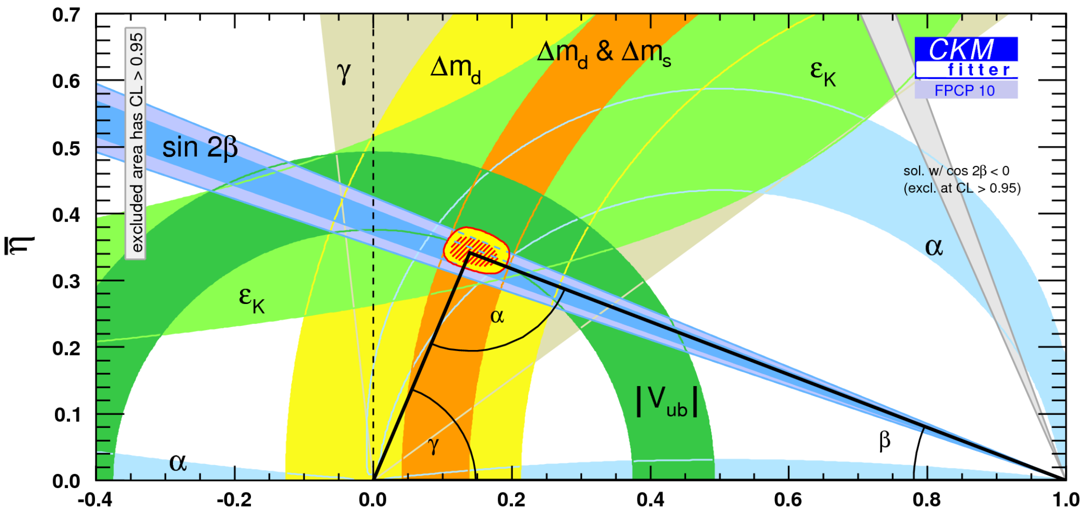


The “Flavour” problem

However if NP is at the TeV scale to solve the hierarchy problem - eg reachable by ATLAS/CMS – it must have a rather sophisticated flavour structure to account for the absence of unambiguous NP signals in FCNC transitions.

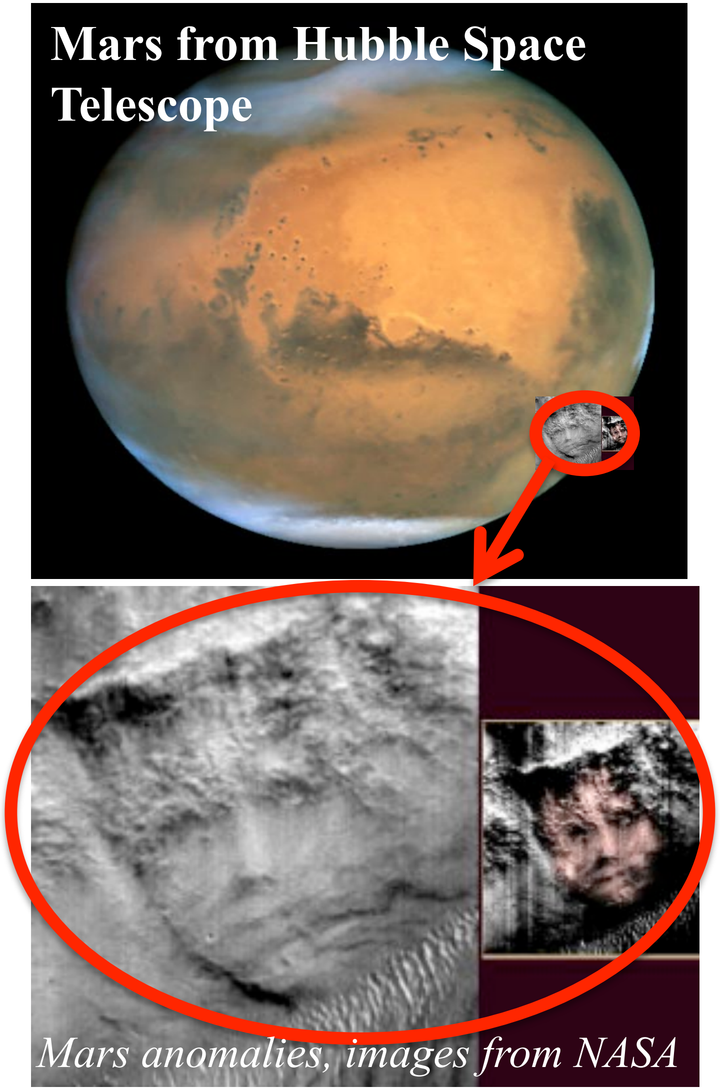


NP [if any] will appear as small anomalies in the Standard Model picture..



The Standard Model works quite (too) well!

Flavour Physics in the LHC era

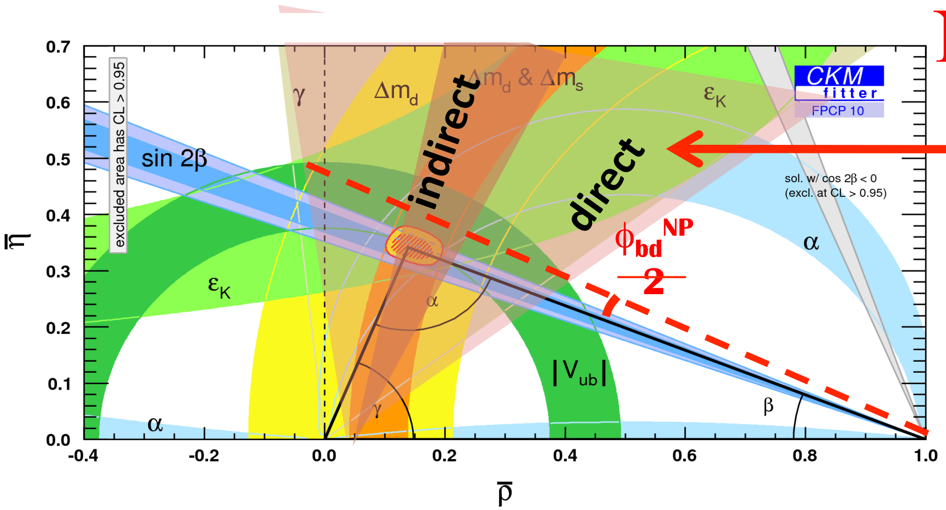


→High statistics and high resolution is required (LHCb now, Belle-II & SuperB tomorrow..) to understand the nature of these anomalies.

"anomalies" in CKM fits

1) A(ψK)= sin(2β) :

→ tension [2.6 σ] between direct measurement and its predictions [ε_K & V_{ub}]



Non-SM phases in B_d mixing?

A precise measurement of γ from tree processes and improved precision in V_{ub} will show if there are new phases involved in B_d mixing processes.

“anomalies” in CKM fits

1) A(ψK)= sin(2β) :

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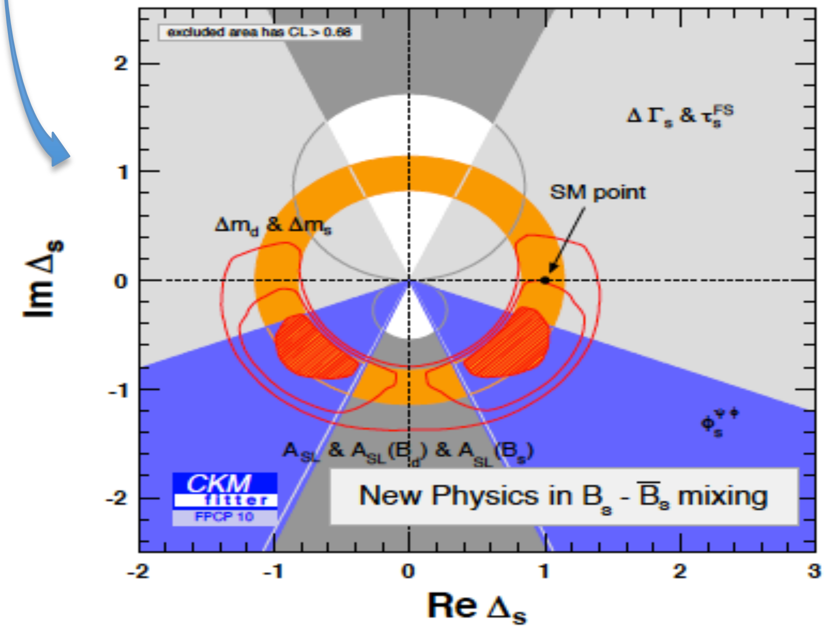
2) CPV in B_s mixing::

mainly driven by same-charge dimuon asymmetry measured by D0 [3.2 σ discrepancy with SM]



Includes A_{sl} from D0 but not 2010 measurements from CDF&D0 of β_s

Non-SM phases in B_s mixing?

$$\left\langle B_q^0 \middle| M_{12}^{SM+NP} \middle| \overline{B}_q^0 \right\rangle \equiv \Delta_q^{NP} \cdot \left\langle B_q^0 \middle| M_{12}^{SM} \middle| \overline{B}_q^0 \right\rangle$$

$$\Delta_q^{NP} = \mathrm{Re}(\Delta_q) + i\ Im(\Delta_q) = |\Delta_q| e^{i\phi^{\Delta_q}} = r_q^2 e^{2i\theta_q} = 1 + h_q e^{2i\sigma_q}$$

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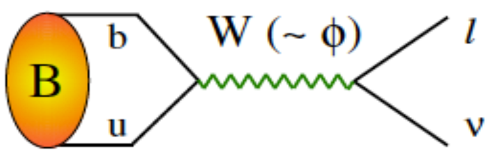
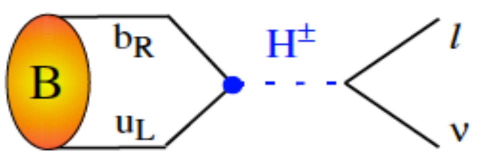
3) BR($B \to \tau\nu$): → exp = $(1.68 \pm 0.31)\ 10^{-4}$ [Babar + Belle ‘10]

→ SM = $(0.79 \pm 0.07)\ 10^{-4}$ [UTFit ’10]



longitudinal comp. of the W



extra tree-level contribution
simple M_H & $\tan\beta$ dependence

Contribution of non-SM Higgs(es)?

$$B(B \to l\nu) = B_{SM} \left(1 - \frac{m_B^2 \tan\beta^2}{M_H^2 (1 + \epsilon_0 \tan\beta)} \right)^2$$

$$B(B \to l\nu)_{SM} = C_0\, f_B^2\, |V_{ub}|^2$$

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Understanding these [and other] anomalies is the role of Flavour Physics in the coming years.

Where to look for NP signals @ LHCb?

1) NP contributions in Rare decays (FCNC processes)

- BR($B_{s,d} \to \mu\mu$), $D^0 \to \mu\mu$
- forward-backward asymmetry in $B_d \to K^*\mu\mu$
- non-SM photon polarization in exclusive $b \to s\gamma$ decays

2) NP contributions in CP violating decays:

a) in box diagrams :

- B_s mixing phase with $B_s \to J/\psi\varphi$ (and $B_s \to J/\psi\ f_0$)
- CP phase in D mixing

b) in penguin diagrams:

Compare two measurements of a given CP asymmetry,
in processes with and without penguins
$\to$any discrepancy is sign of New Physics

- $\sin(2\beta)$ from $B^0 \to J/\psi K_S$ and $\sin(2\beta)$ from $B^0 \to \phi K_S$
- γ from $B_{(s)} \to D_{(s)}K$ and γ from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$
- βs from $B_s \to J/\psi\varphi$ (f_0) and $B_s \to \varphi\varphi$

8

3) LFV decays with muons in the final state: eg $\tau \to \mu\mu\mu$

Where to look for NP signals @ LHCb?

The editor's choice

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b) in penguin diagrams:

Compare two measurements of a given CP asymmetry, in processes with and without penguins
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- sin(2β) from $B^0 \rightarrow J/\psi K_S$ and sin(2β) from $B^0 \rightarrow \phi K_S$
- **γ from $B_{(s)} \rightarrow D_{(s)}K$** and γ from $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$
- β_s from $B_s \rightarrow J/\psi\varphi$ (f_0) and $B_s \rightarrow \varphi\varphi$

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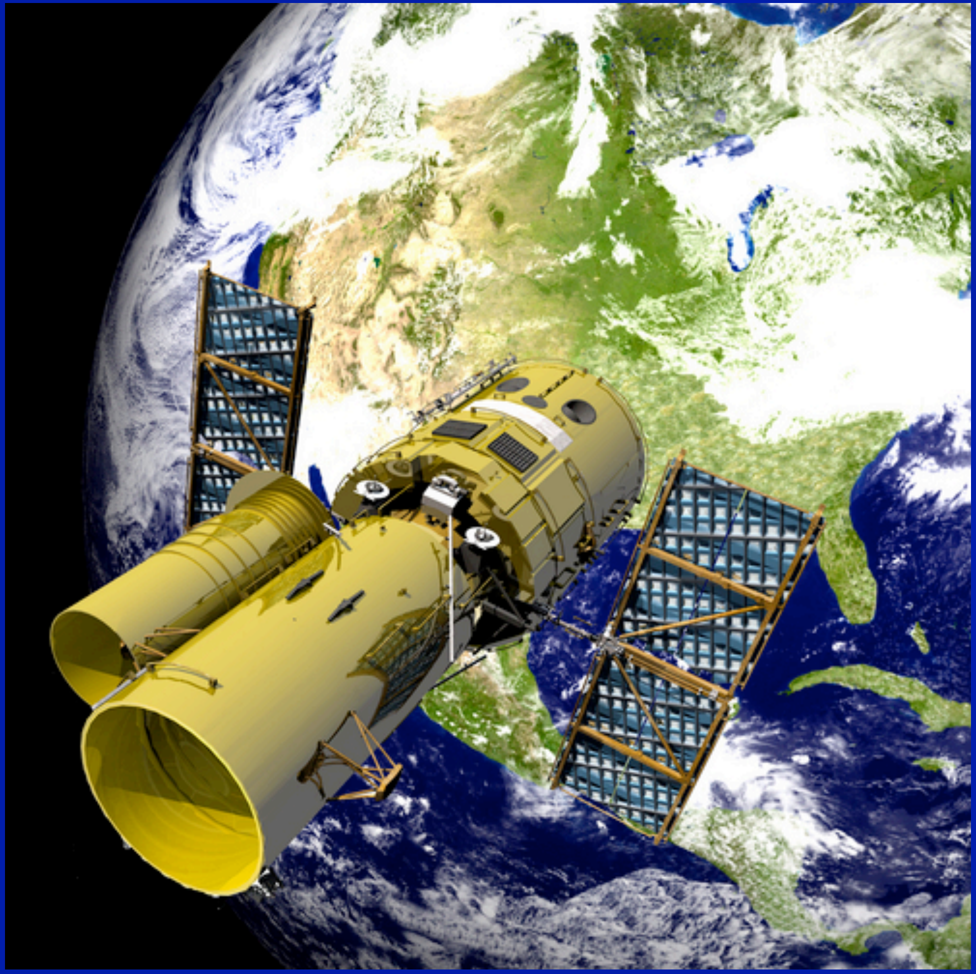
8

2. LHC machine and LHCb detector performance

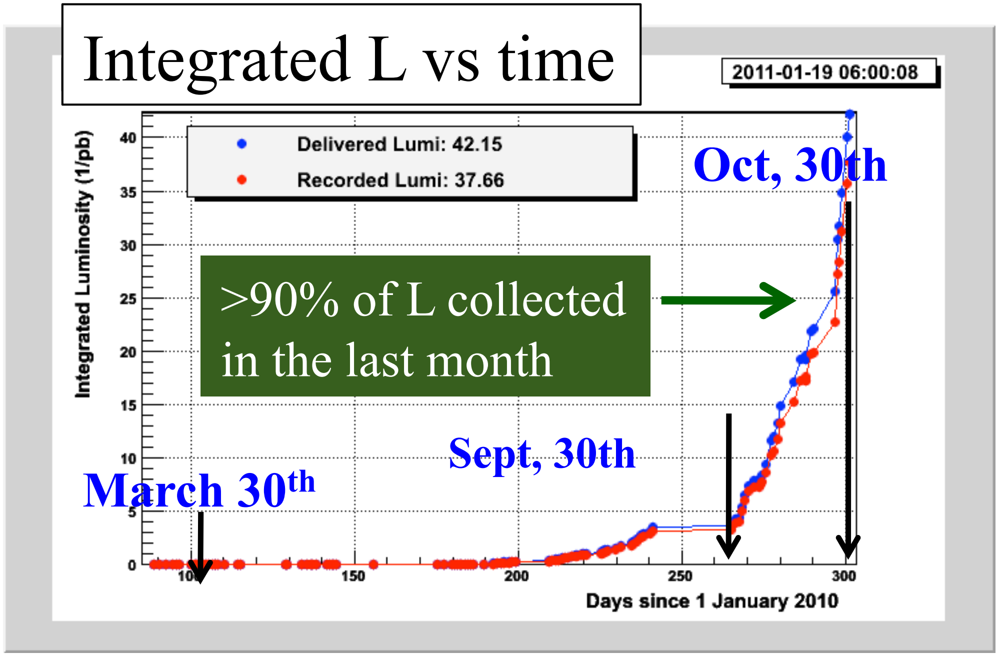


The Hubble space telescope

LHC: the 2010 run and perspectives for 2011

- 2010 run @ √s = 7 TeV - a "glorious" run:

L_{peak} increased x10/month, >90% L collected in 20 days!
$L_{int} \sim 42/38\ pb^{-1}$ (delivered/recorded) with $L_{peak} \sim 1.6 \times 10^{32}\ cm^{-2}\ s^{-1}$



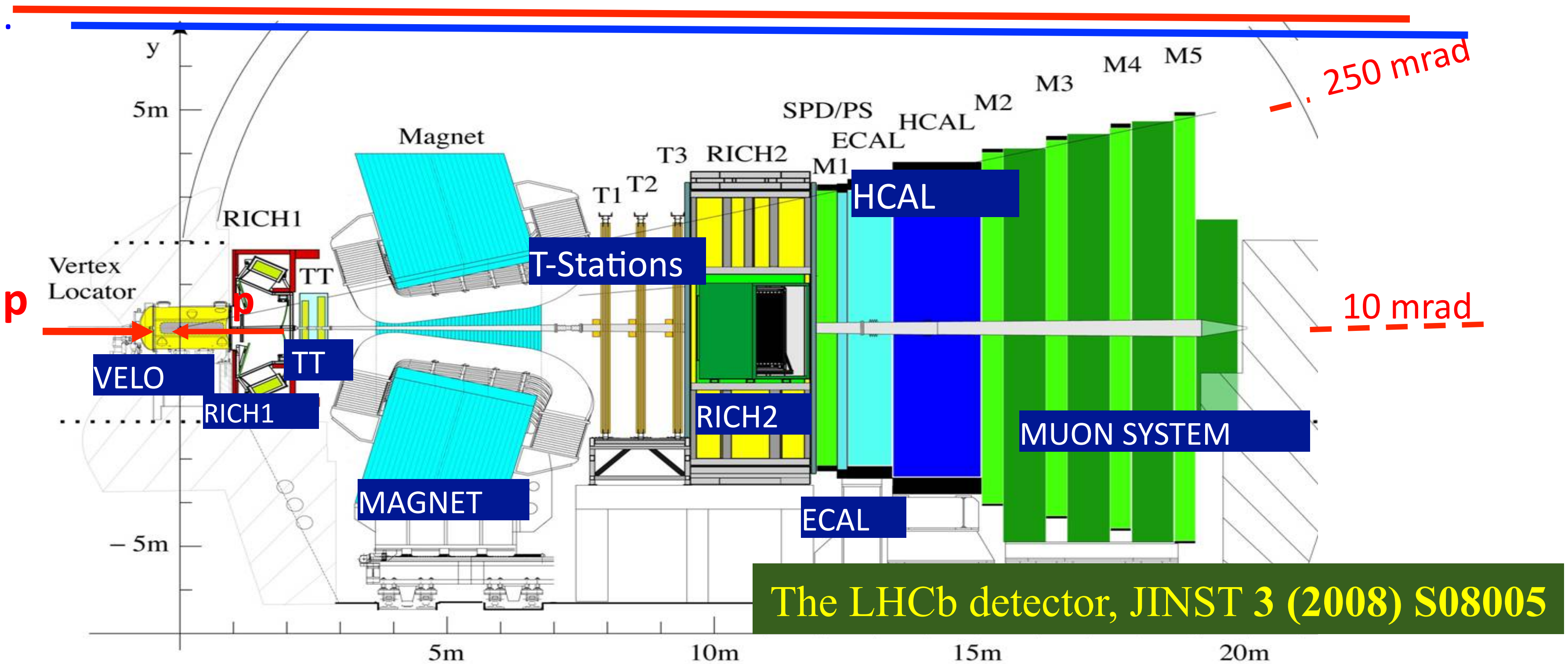
LHCb, σ(pp→bb @ 7 TeV)~ 300 ub (*)
L ~ 38 pb^{-1} → ~10^{10} bb-pairs produced
(B^+, B_d, B_s, Λ_b)
Babar+Belle @ ϒ(4S),
L ~ 1.5 ab^{-1} → 1.5 10^9 bb pairs produced (only B^+, B_d)

(*) *LHCb, Phys.Lett.B 694 (2010) 209*

-2011 run @ √s = 7 TeV – the close future:

LHC just resumed the operations
LHCb expects to collect 1 fb^{-1} in 2011

LHCb at the LHC



LHCb skills for Rare and CP-violating b- (and c-) decays:

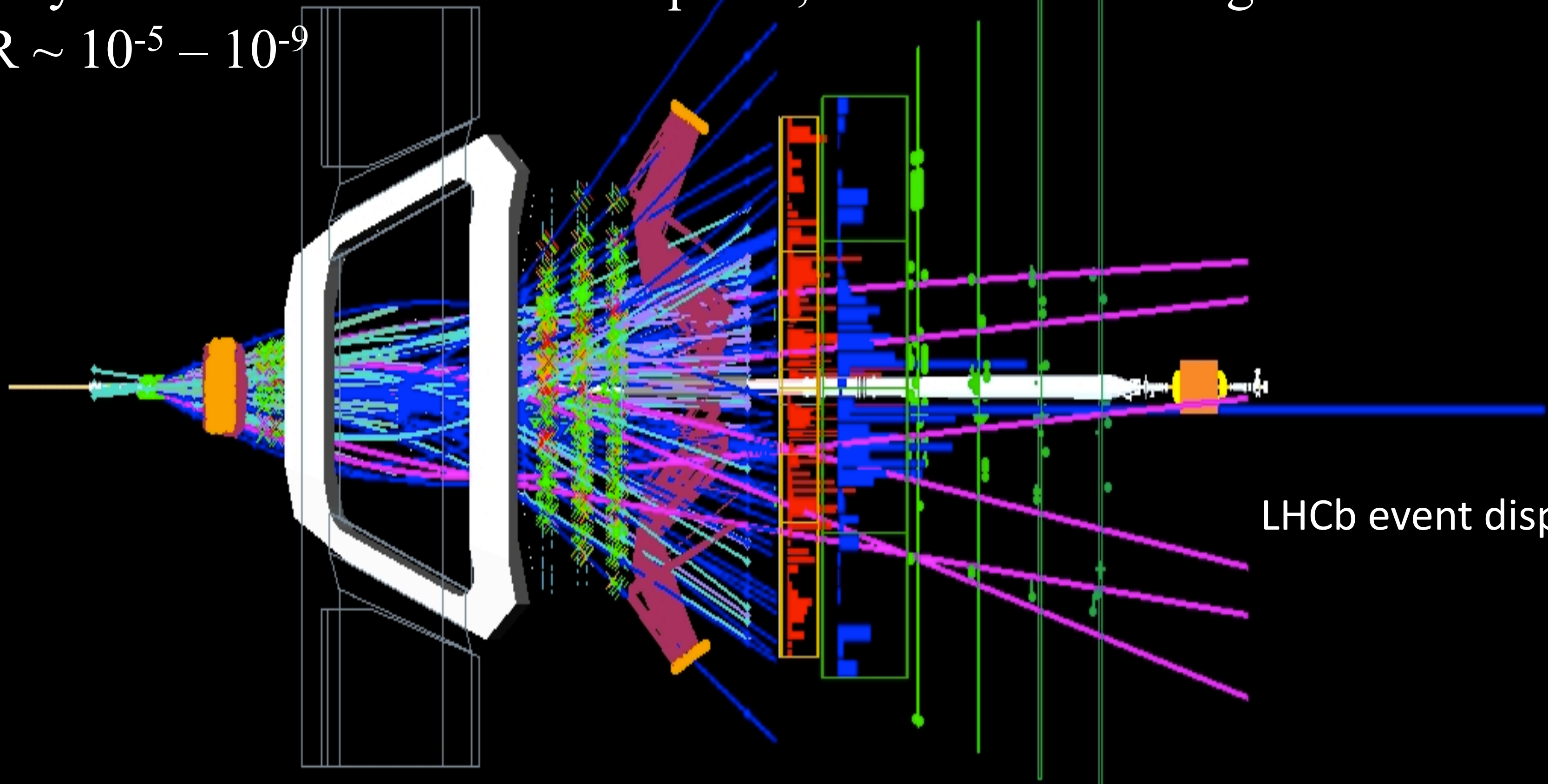
- ❒ Huge cross sections: **σ(pp→bb(cc)X) @ 7 TeV ~ 300 μb (6 mb)**
- ❒ Large acceptance (bb are produced forward/backward):

  LHCb acceptance **1.9<η<4.9** (CDF: |η|<1 ; D0: |η|<2; CMS/ATLAS:|η|<2.4)
- ❒ Large boost: → **average flight distance of B mesons ~ 10 mm**

→ A huge amount of very displaced b's…….

…. But in a harsh environment!

- σ(pp, inelastic) @ $\sqrt{s}$=7 TeV ~ 60 mb
  - 80 tracks per event in 'high'-pileup conditions (~2.5 pp interactions/Xing)
  - only 1/200 event contains a b quark , and we are looking for BR ~ $10^{-5} – 10^{-9}$



LHCb event display

→ Our problem is clearly the background….

Key ingredients for LHCb:
[where we cannot fail]

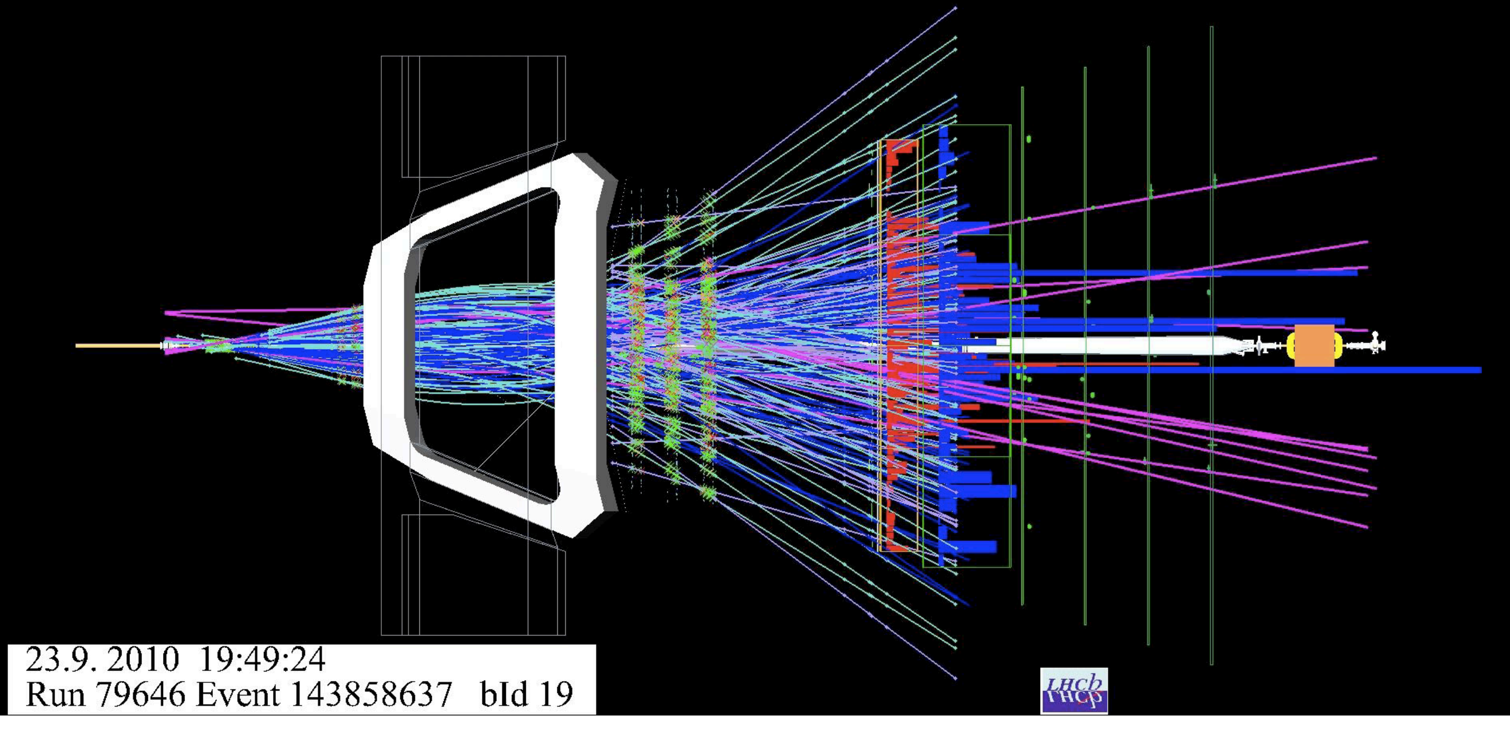
1) Efficient trigger:

- to separate hadronic and leptonic final states from the HUGE background

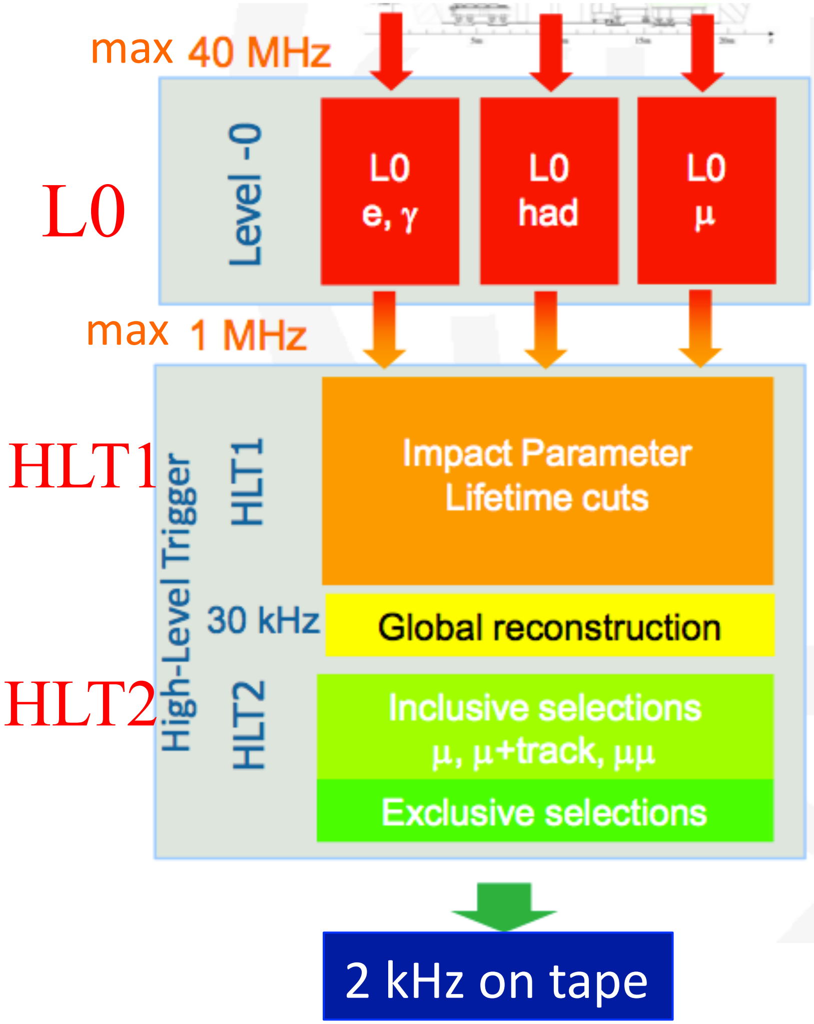
2) Good mass resolution & particle identification:

3) Excellent vertex resolution:

- to resolve fast Bs oscillations and separate signals from background



1. LHCb Trigger



L0 [hardware]	**'High-pt' signals in calorimeter & muon systems**
HLT1 [software]	Associate L0 signals with tracks, especially those in VELO displaced from PV
HLT2 [software]	Full detector information available. Inclusive signatures, augmented by exclusive selections in key channels.

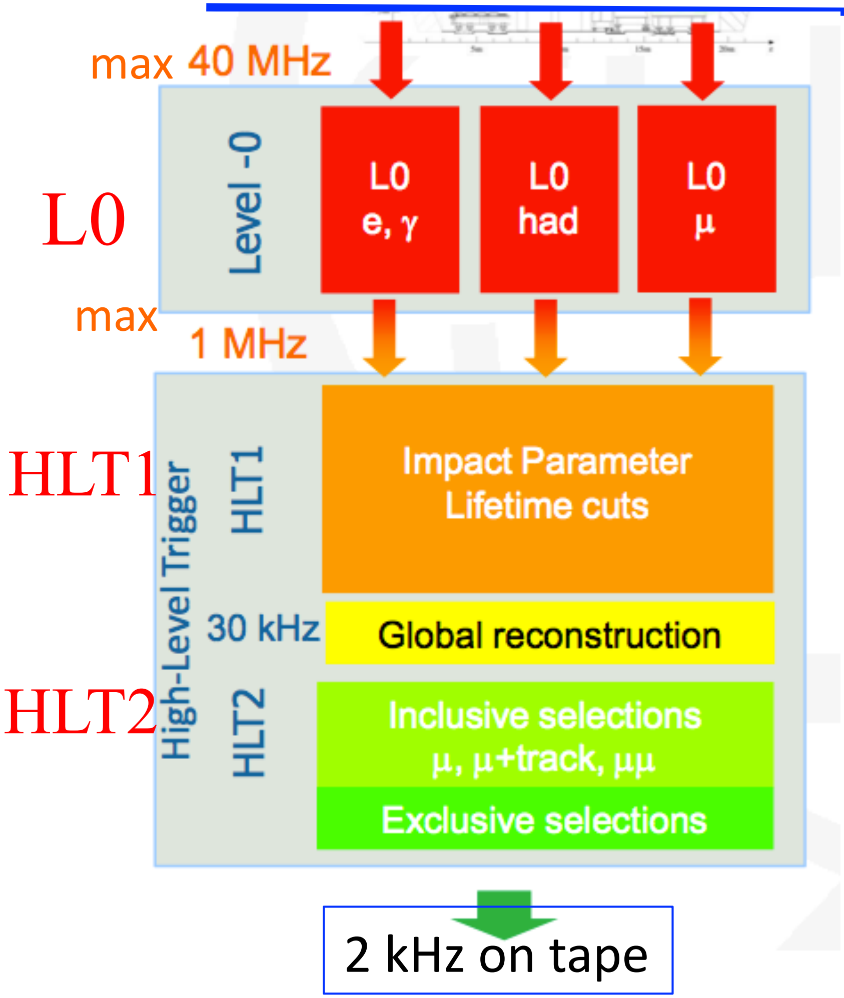
+ Global Event Cuts for events with high multiplicity

Small event size (~60 kB) allows for a large bandwidth → relatively low trigger thresholds → high efficiency

	charm	hadr. B	lept. B
nominal L	~ 10%	~ 40%	~ 90%

Muon Triggers in 2010

(eg: $B_{s,d} \rightarrow \mu\mu$ & $B_s \rightarrow J/\psi\ \varphi$)



	Muon Lines
L0	Single- μ: **p_T> 1.4 GeV/c** μμ: **p_{T1}>0.48 GeV/c** **p_{T2}>0.56 GeV/c**
HLT1	single-μ: p_T>0.8 GeV/c IP>0.11 mm IPS> 5
HLT2	Several dimuon lines with $M_{\mu\mu}$ cuts and/or displaced vertex

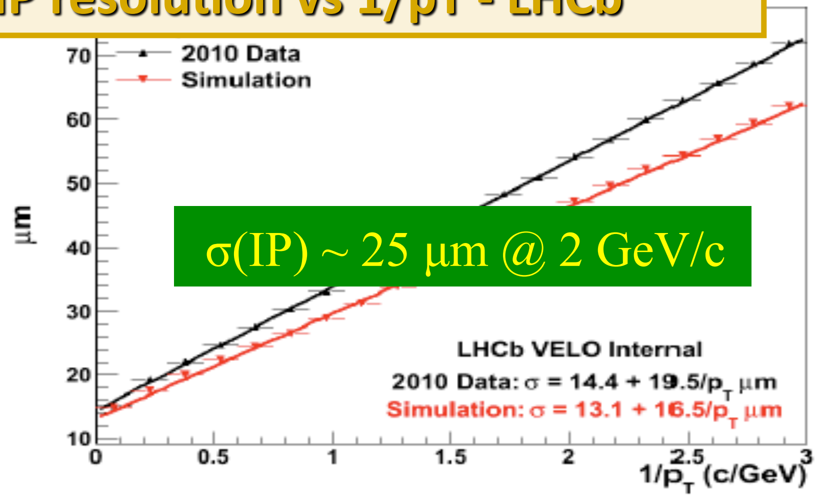
- Half of the bandwidth (~1 kHz) given to the muon lines
- p_T cuts on muon lines kept very low → ε(trigger for di-μ channels) > 90%
- Trigger rather stable during the whole period (despite L increased by ~10^5)

key ingredients for b- [c-]physics: Vertex & IP resolutions

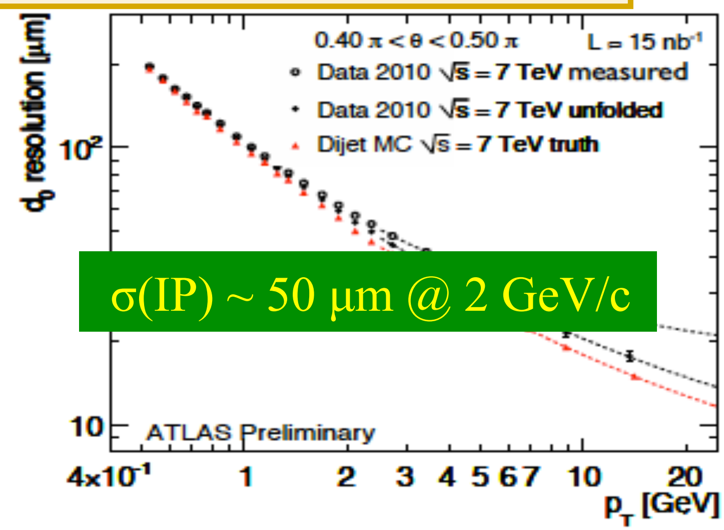
Crucial for time-dependent CP asymmetries: βs, γ, charm, …
Crucial for tagging and background rejection.

Primary vertex resolutions (25 tracks):	LHCb [μm]	ATLAS [μm]	CMS [μm]
σ(x)	15.8	60	20-40
σ(y)	15.2	60	20-40
σ(z)	91.0	100	40-60

IP resolution vs 1/pT - LHCb

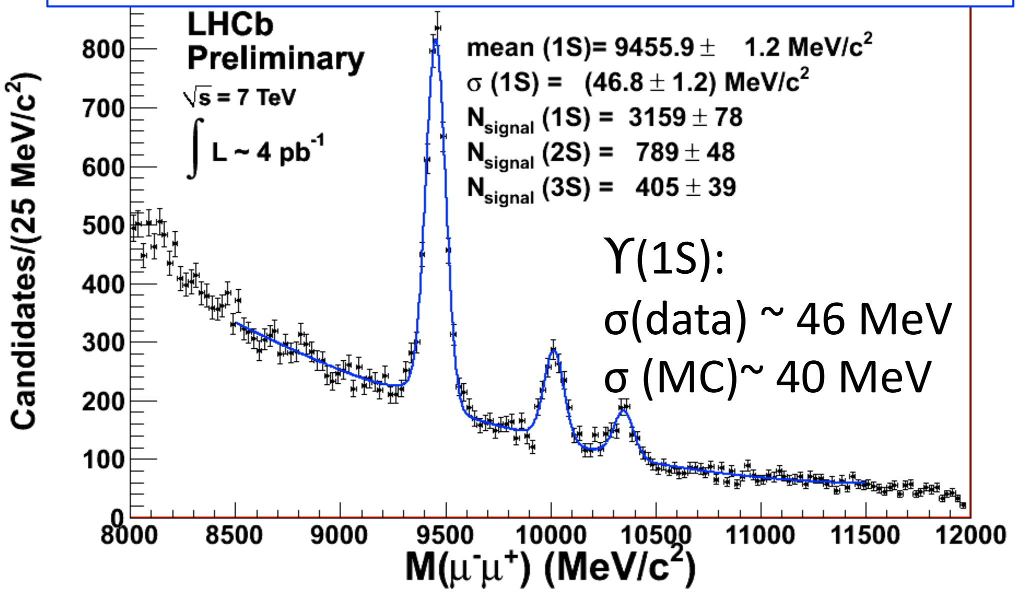


IP resolution vs pT - ATLAS



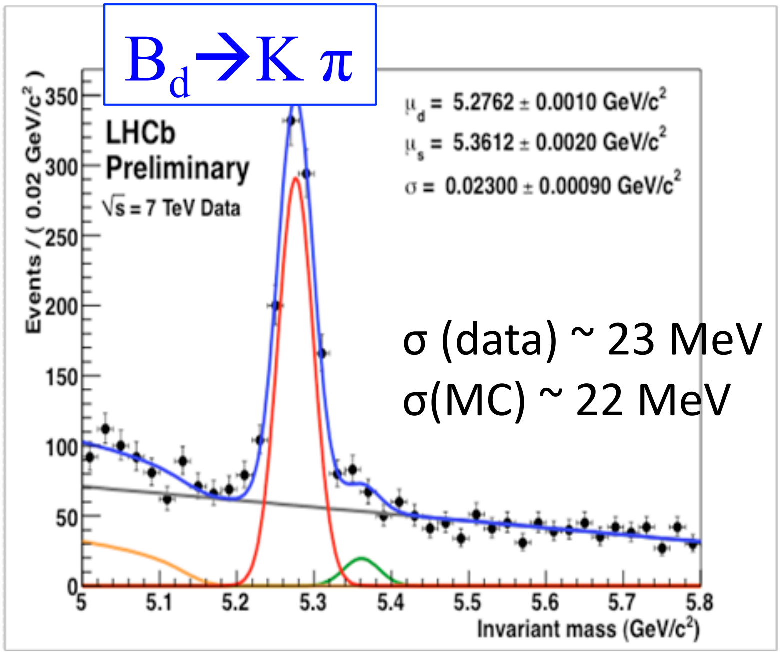
key ingredients for b- [c-]physics: mass resolutions

The Υ family: Υ(1S), Υ(2S), Υ(3S)



Υ(1S):
σ(data) ~ 46 MeV
σ (MC)~ 40 MeV

$B_d \rightarrow K\,\pi$



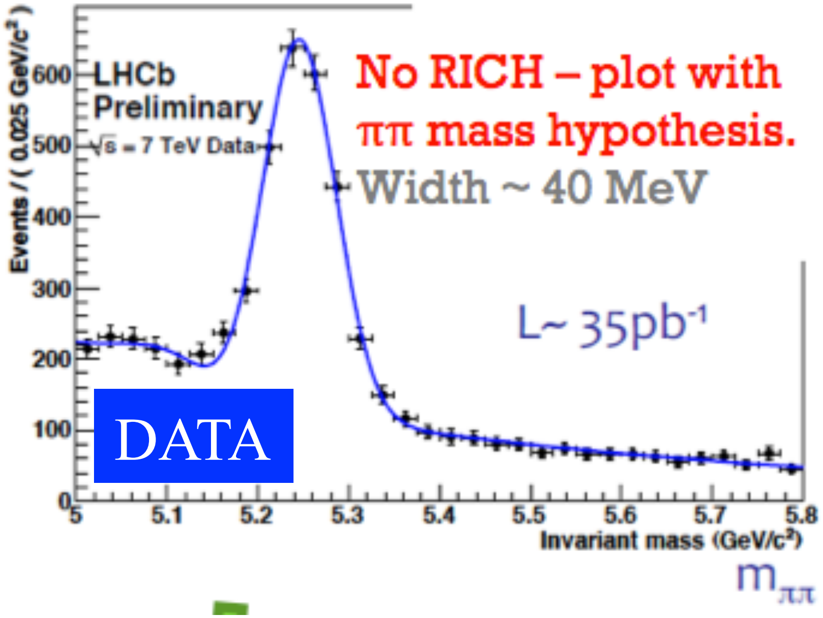
σ (data) ~ 23 MeV
σ(MC) ~ 22 MeV

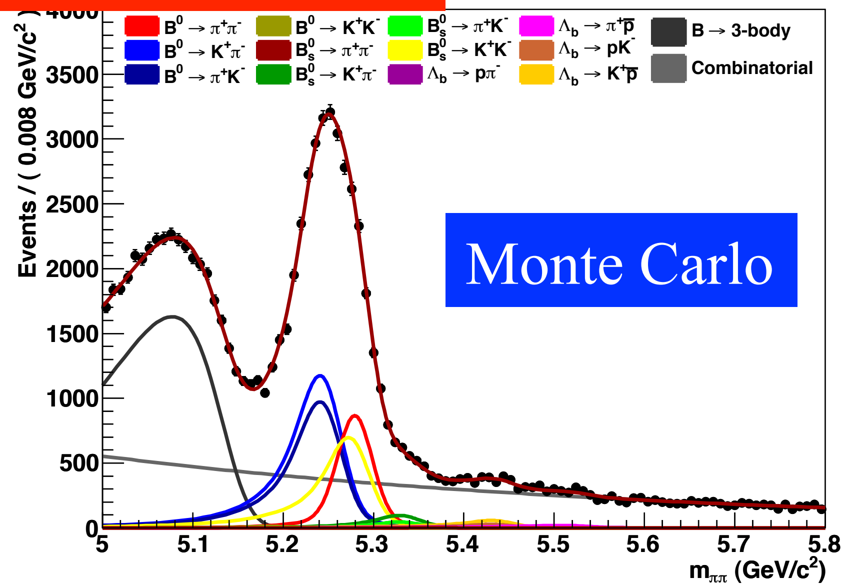
	p-resolution	Mass resolution $J/\psi \rightarrow \mu\mu$
LHCb	$\delta p/p$ = 0.4-0.6 %	13 MeV
CMS	$\delta pt/pt$ = 1-3 %	40 MeV
ATLAS	$\delta pt/pt$ = 5-6 %	71 MeV

key ingredients for b- [c-]physics: RICH PID

Crucial for γ from trees [B→D K], charm physics and b-tagging:

$B_{(s,d)}$→ hh’ peak WITHOUT RICH





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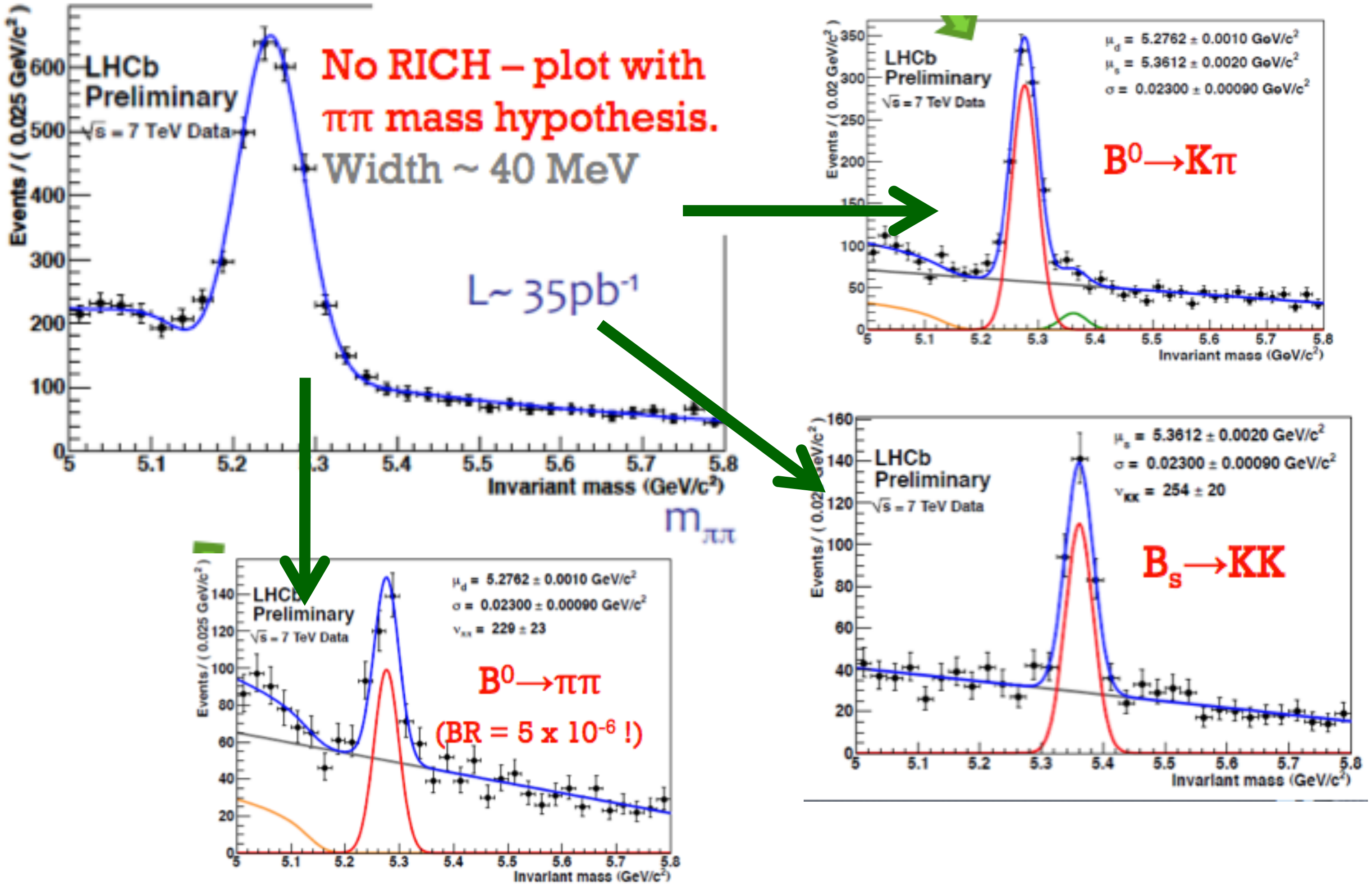
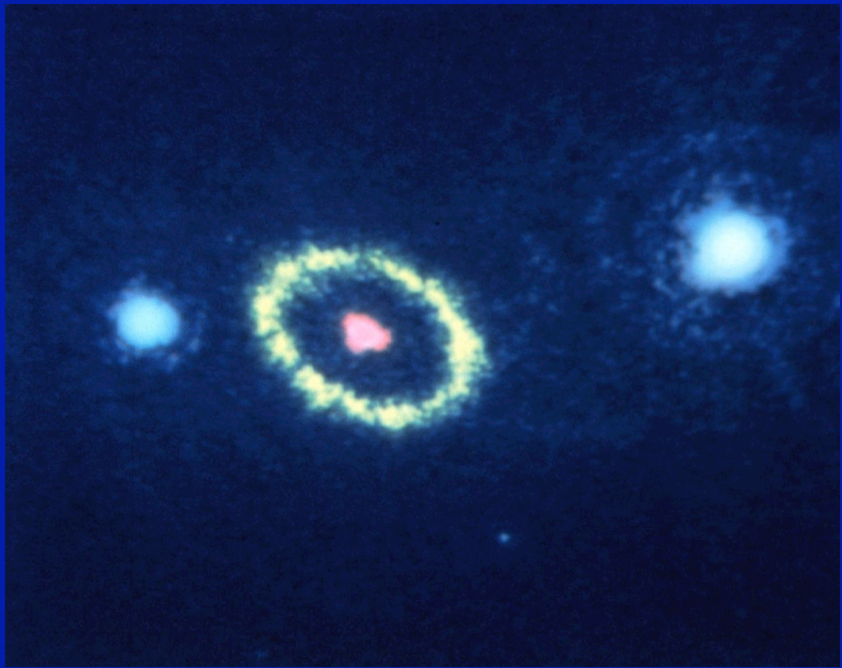


We have all the arms to attack our core physics program:

3. First flavour physics results



First images from the space:

"August 29, 1990: The Hubble Space Telescope has resolved, to an unprecedented detail of 0.1 arcsecond, a mysterious elliptical ring of material around the remnants of Supernova 1987A. "

Where to look for NP signals @ LHCb?

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  1) **BR($B_{s,d} \to \mu\mu$)**, $D^0 \to \mu\mu$
  2) forward-backward asymmetry in $B_d \to K^*\mu\mu$
  3) non-SM photon polarization in exclusive $b \to s\gamma$ decays

The editor's choice

(brand new result presented in La Thuile 10 days ago)
arXiv:1103.2465
Submitted to Phys.Lett.B

-NP contributions in CP violating decays:
  1) in box diagrams :
    - B_s mixing phase with $B_s \to J/\psi\varphi$ (and $B_s \to J/\psi\ f_0$)
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    Compare two measurements of a given CP asymmetry, in processes with and without penguins
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    - $\sin(2\beta)$ from $B^0 \to J/\psi K_S$ and $\sin(2\beta)$ from $B^0 \to \phi K_S$
    - γ from $B_{(s)} \to D_{(s)}K$ and γ from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$
    - betas from $B_s \to J/\psi\varphi$ (f_0) and $B_s \to \varphi\varphi$

-LFV decays with muons in the final state: eg $\tau \to \mu\mu\mu$

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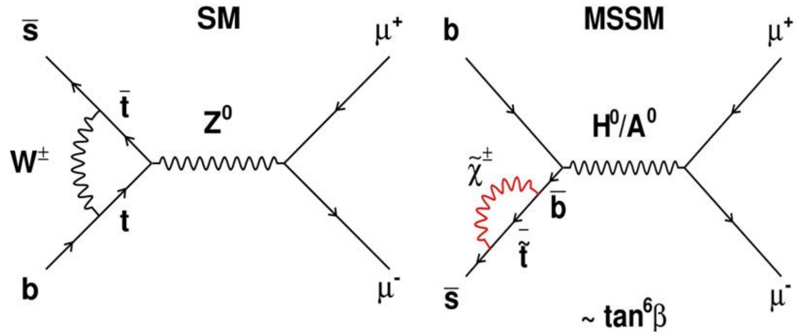
$B_{s,d} \rightarrow \mu\mu$: the LHCb hunt for non-SM Higgs(es)

$B_{(d,s)} \rightarrow \mu\mu$ is the best way for LHCb to constrain the parameters of the extended Higgs sector in MSSM, fully complementary to direct searches

$$BR(B_q \to l^+ l^-) \approx \frac{G_F^2 \alpha^2 M_{B_q}^3 f_{B_q}^2 \tau_{B_q}}{64\pi^3 \sin^4\theta_W} |V_{tb} V_{tq}^*|^2 \sqrt{1 - \frac{4m_l^2}{M_{B_q}^2}} \left\{ M_{B_q}^2 \left(1 - \frac{4m_l^2}{M_{B_q}^2}\right) c_S^2 + \left[M_{B_q} c_P + \frac{2m_l}{M_{B_q}} (c_A - c'_A) \right]^2 \right\}.$$



Double suppressed decay: **FCNC process** and **helicity suppressed**:

→ **very small in the Standard Model but very well predicted:**

$$\mathbf{B_s \rightarrow \mu^+\mu^- = (3.2 \pm 0.2) \times 10^{-9}} \qquad \mathbf{B_d \rightarrow \mu^+\mu^- = (1.0 \pm 0.1) \times 10^{-10}}$$

Buras et al., arXiv:1007.5291

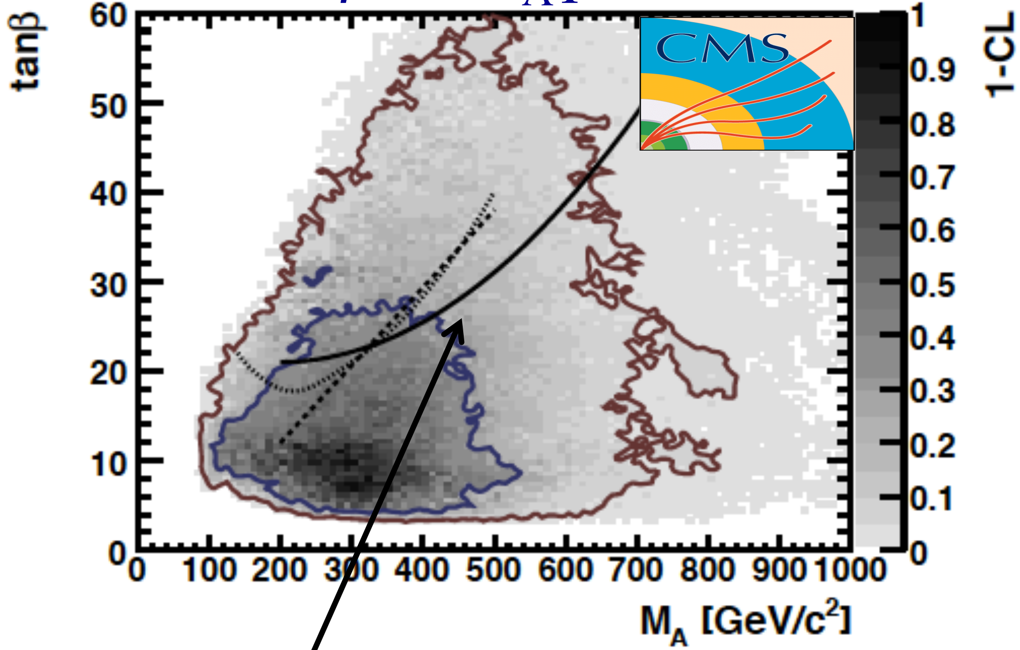
→ **sensitive to New Physics** contributions in the **scalar/pseudo-scalar sector:**

$$(\, c_{S,P}^{MSSM} \,)^2 \propto \left(\frac{m_b m_\mu \tan^3\beta}{M_A^2} \right)^2$$

MSSM, large tanβ approximation

$B_{s,d} \rightarrow \mu\mu$: the LHCb hunt for non-SM Higgs(es)

tanβ vs M_A plane



Best fit contours in tanβ vs M_A plane in the NUHM1 model

[O. Buchmuller et al, arxiv:0907.5568]

5σ discovery contours for observing the **heavy MSSM Higgs bosons H, A** in the three decay channels **H,A→$\tau^+\tau^-$ → jets (solid line), jet+μ (dashed line)**, **Jet+e (dotted line) assuming 30-60 fb^{-1} collected by CMS.**

$B_{s,d} \rightarrow \mu\mu$: the LHCb hunt for non-SM Higgs(es)

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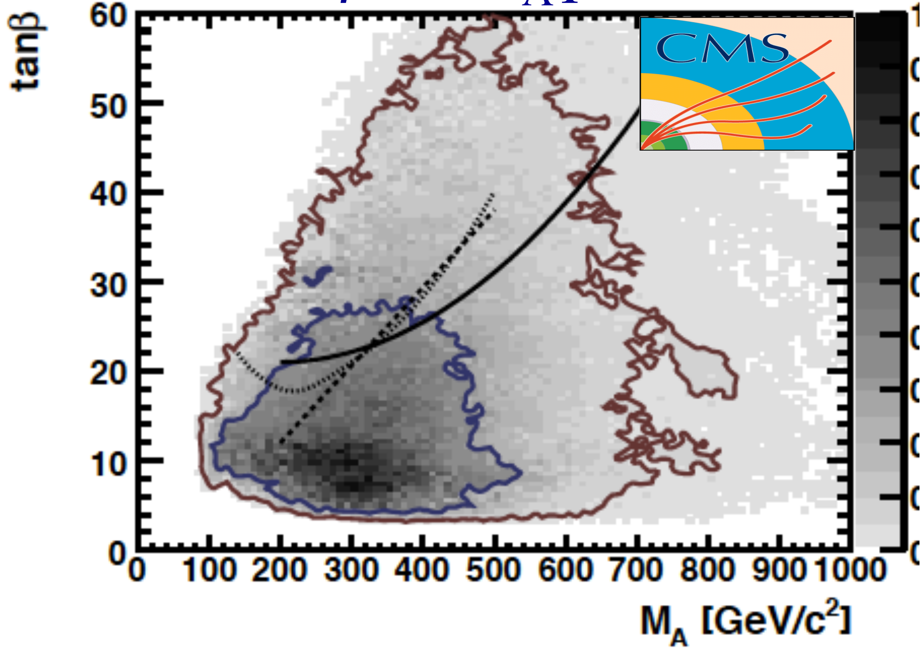
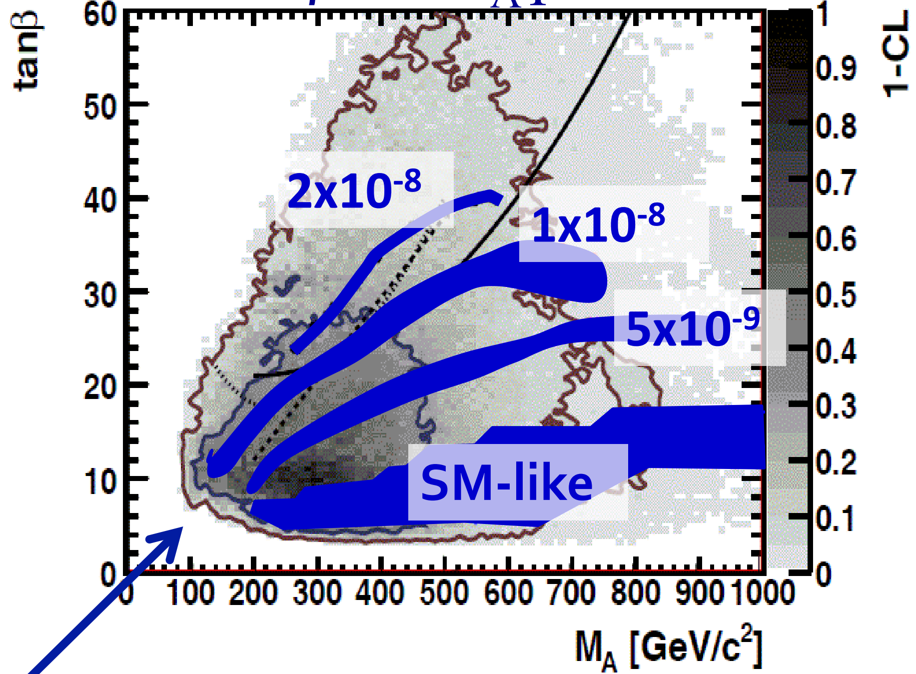


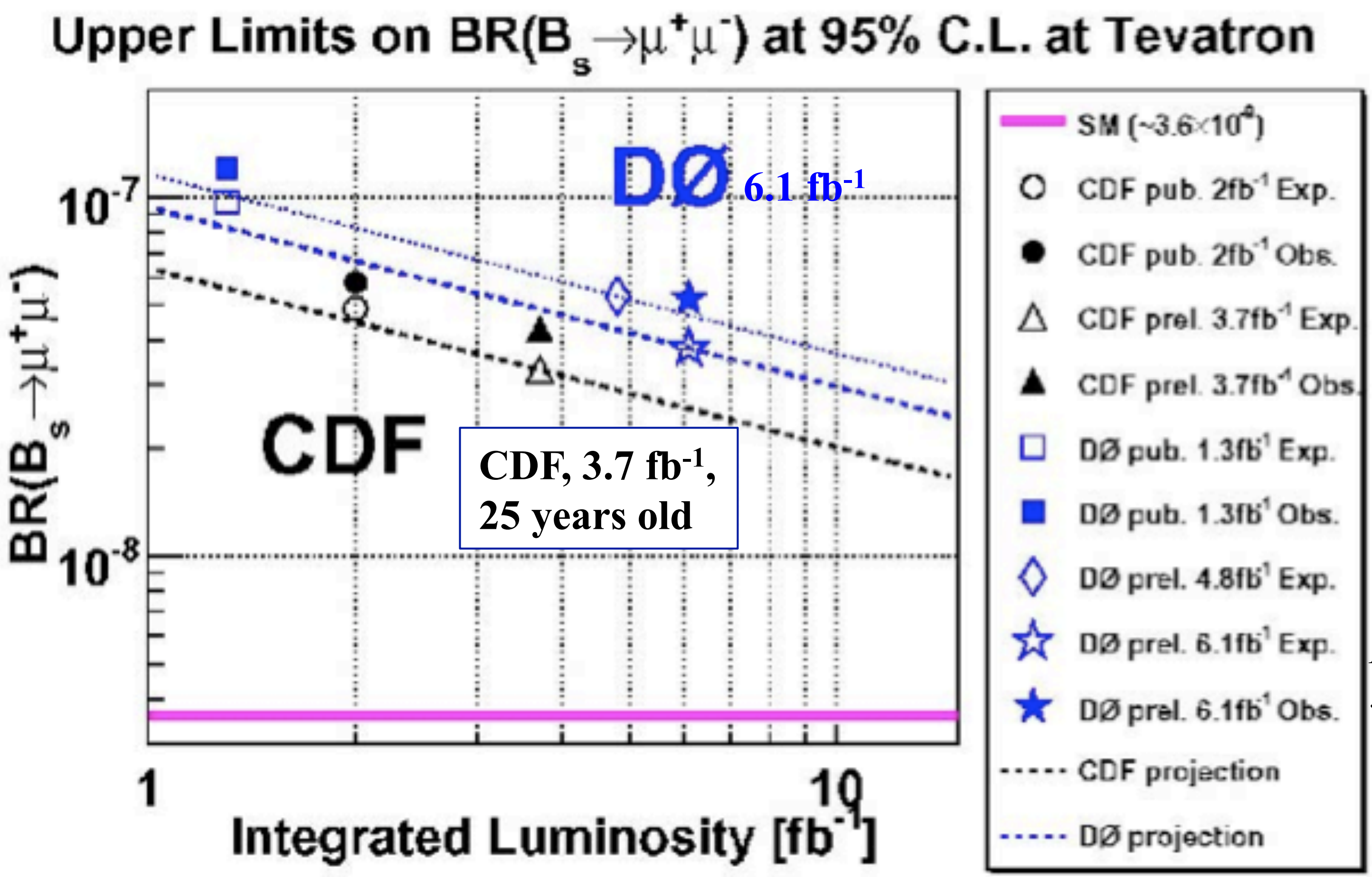
tanβ vs M_A plane



Regions compatible with $BR(B_s \rightarrow \mu\mu) = 2x10^{-8}$, $1x10^{-8}$, $5x10^{-9}$ and SM.

LHCb calculation using F. Mahmoudi, SuperIso, arXiv: 08083144

$B_{s,d} \rightarrow \mu\mu$: current experimental results

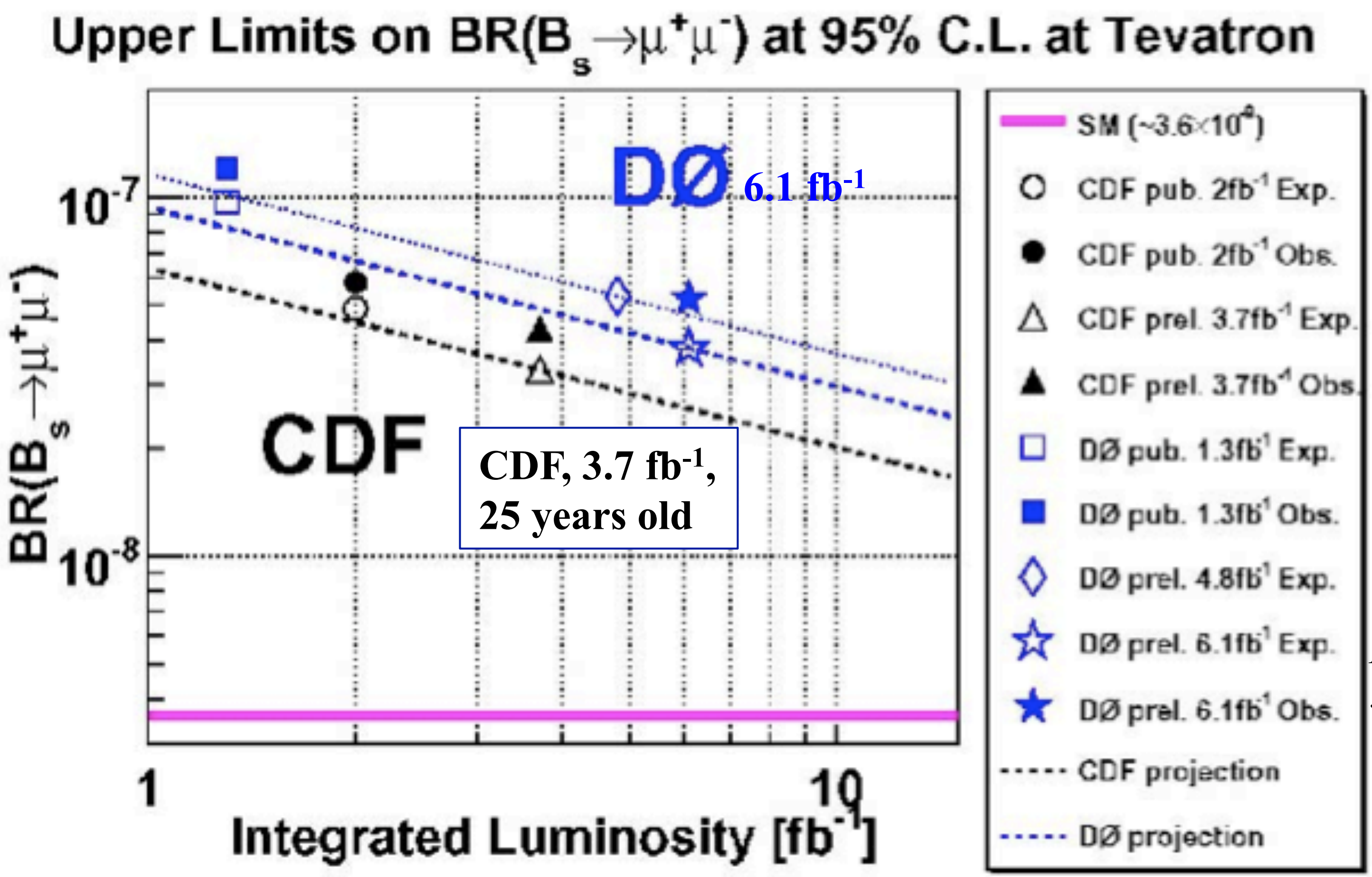


PLB 693, 539 (2010)

- Limits from Tevatron @ 95% CL:
  - CDF (~3.7 fb^{-1}): B_S (B_d) → μμ < **43 (7.6) ×10^{-9}**
  - D0 (~6.1 fb^{-1}): B_S→μμ < **51×10^{-9}**

$B_{s,d} \rightarrow \mu\mu$: current experimental results

LHCb,
10 months old
37 pb^{-1}
(33 pb^{-1} collected in 15 days!)



PLB 693, 539 (2010)

- Limits from Tevatron @ 95% CL:
  - CDF (~3.7 fb^{-1}): B_s (B_d) $\rightarrow \mu\mu$ **< 43 (7.6) ×10^{-9}**
  - D0 (~6.1 fb^{-1}): $B_s \rightarrow \mu\mu$ **< 51×10^{-9}**

$B_{s,d} \rightarrow \mu\mu$: analysis strategy

- Soft selection:

  - reduces the dataset to a manageable level

- Discrimination between S and B via Multi Variate Discriminant variable (GL) and Invariant Mass (IM)

  - events in the sensitive region are classified in bins of a 2D plane Invariant Mass and the GL variables

- Normalization:

  Convert the signal PDFs into a number of expected signal events by normalizing to channels of known BR

- Extraction of the limit:

  - assign to each observed event a probability to be S+B or B-only as a function of the BR($B_{s,d} \rightarrow \mu\mu$) value; exclude (observe) the assumed BR value at a given confidence level using the **CLs binned method.**

$B_{s,d} \rightarrow \mu\mu$: soft selection

Soft selection:

(pairs of opposite charged muons with high quality tracks, making a common vertex very displaced with respect to the PV and $M_{\mu\mu}$ in the range [4769-5969] MeV/c^2)

1) Keeps high efficiency for signals:

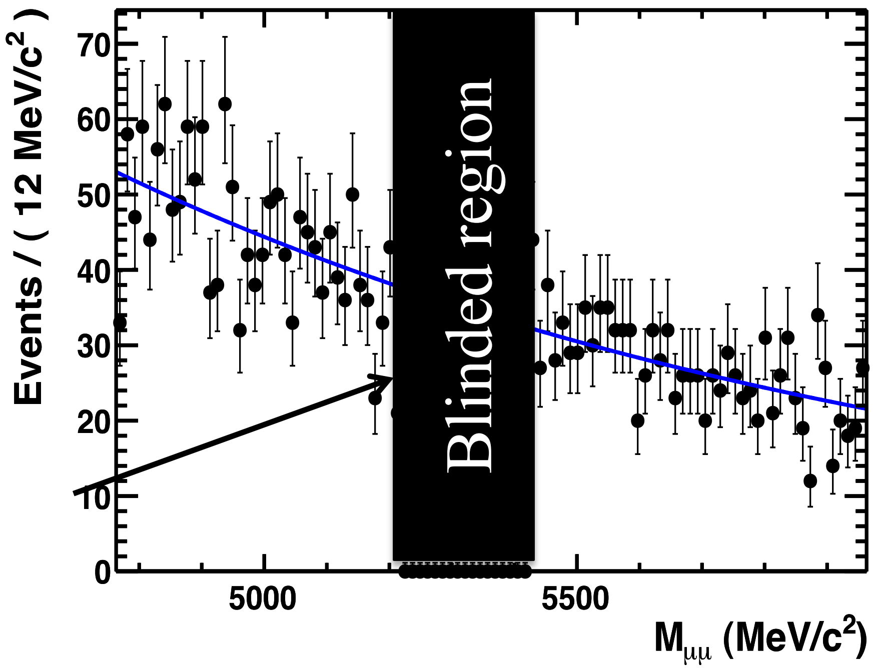
After selection **$B_s(B_d) \rightarrow \mu\mu$ events expected (if BR=BR(SM)): 0.3 (0.04)**

3) Rejects most of the background

→ ~ 3000 background events in the large mass range [4769-5969] MeV/c^2

~ 300 background events in the signal windows:

$M(B_{s,d}) \pm 60$ MeV

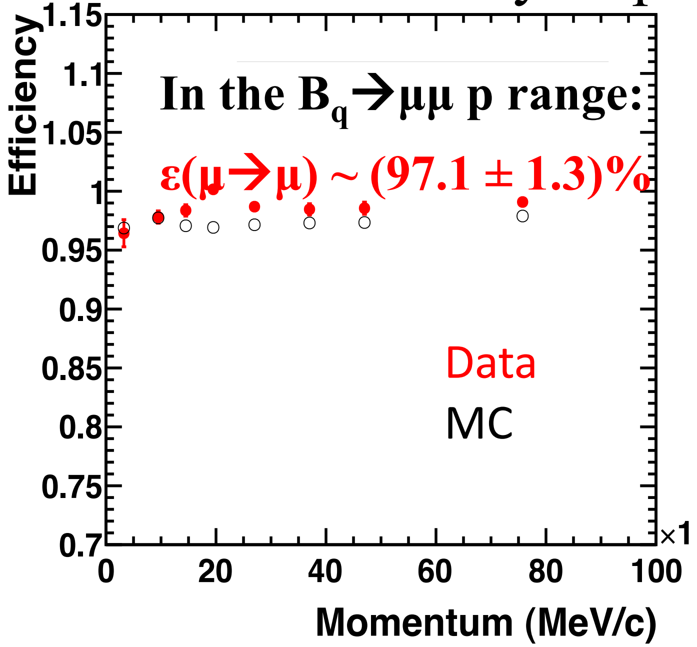


Signal regions
blinded up to the analysis end

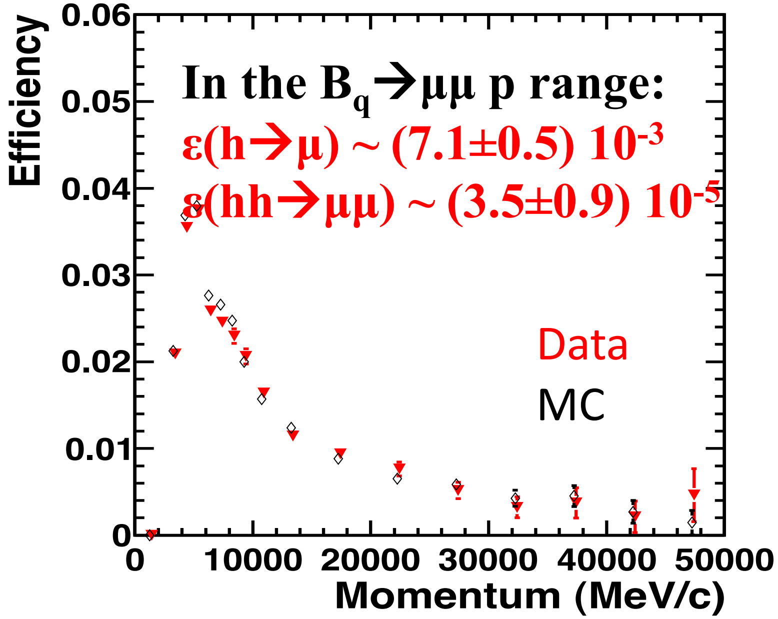
MuonID performance & background composition

Performance measured with pure samples of $J/\psi \rightarrow \mu\mu$, $K_s \rightarrow \pi\pi$, $\varphi \rightarrow KK$, $\Lambda \rightarrow p\,\pi$

MuonID efficiency vs p



$\pi \rightarrow \mu$ misidentification rate vs p



We are dominated by the $bb \rightarrow \mu\mu X$ component

(double semi-leptonic decays and cascade processes)

fake+μ ~ 10% and double fake ~0.3%

Peaking background ($B \rightarrow hh'$) fully negligible

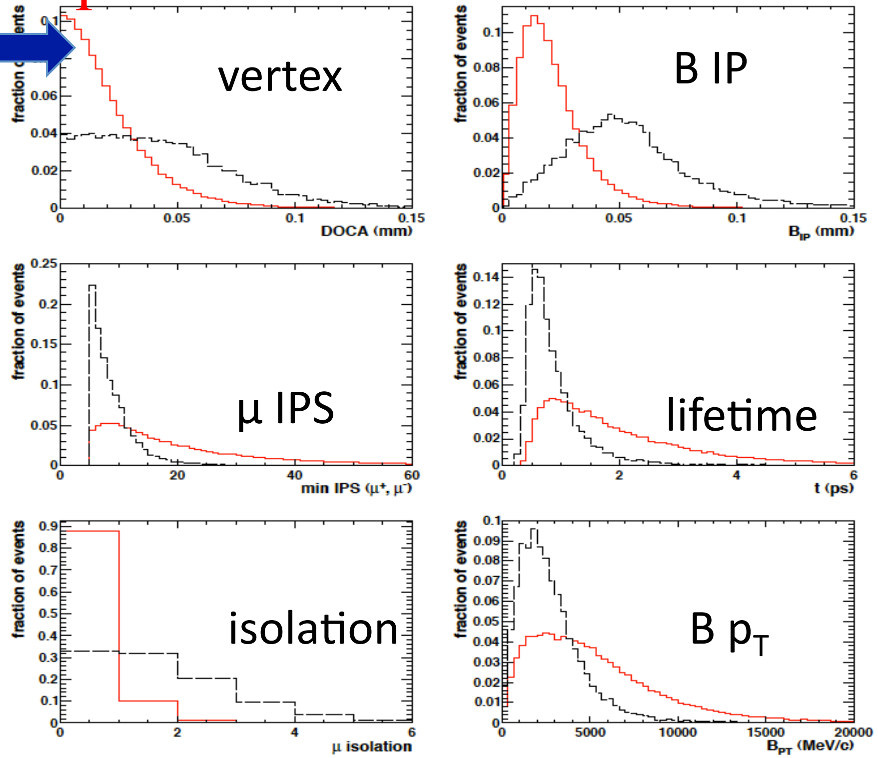
(< 0.1 events in signal regions)

$B_{s,d} \rightarrow \mu\mu$: Geometrical Likelihood (GL)

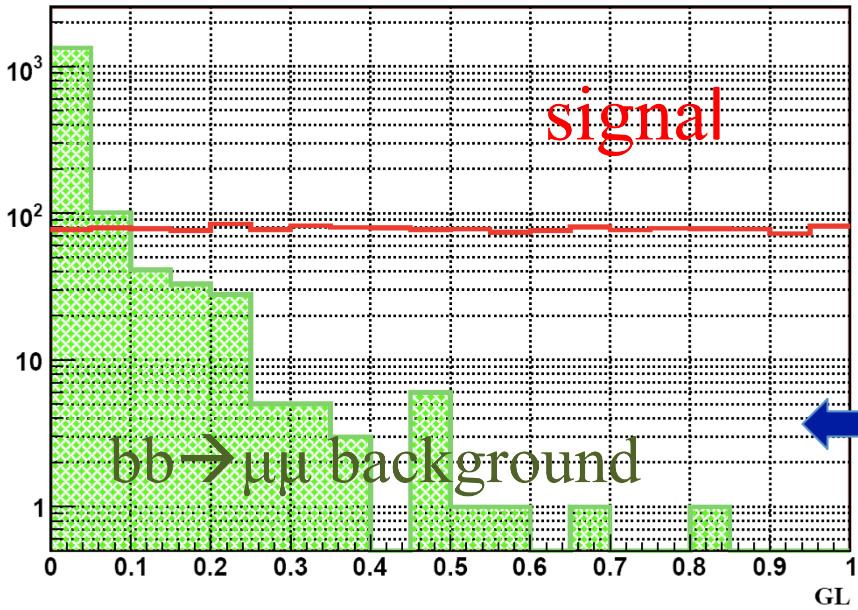
Our main background is combinatorial background from two real muons:

→ reduce it by using variables related to the "geometry" of the event:
(vertex, pointing, μ IPS, lifetime, mu-isolation) + p_T of the B

Input Variables to the GL



Geometrical Likelihood (MC)

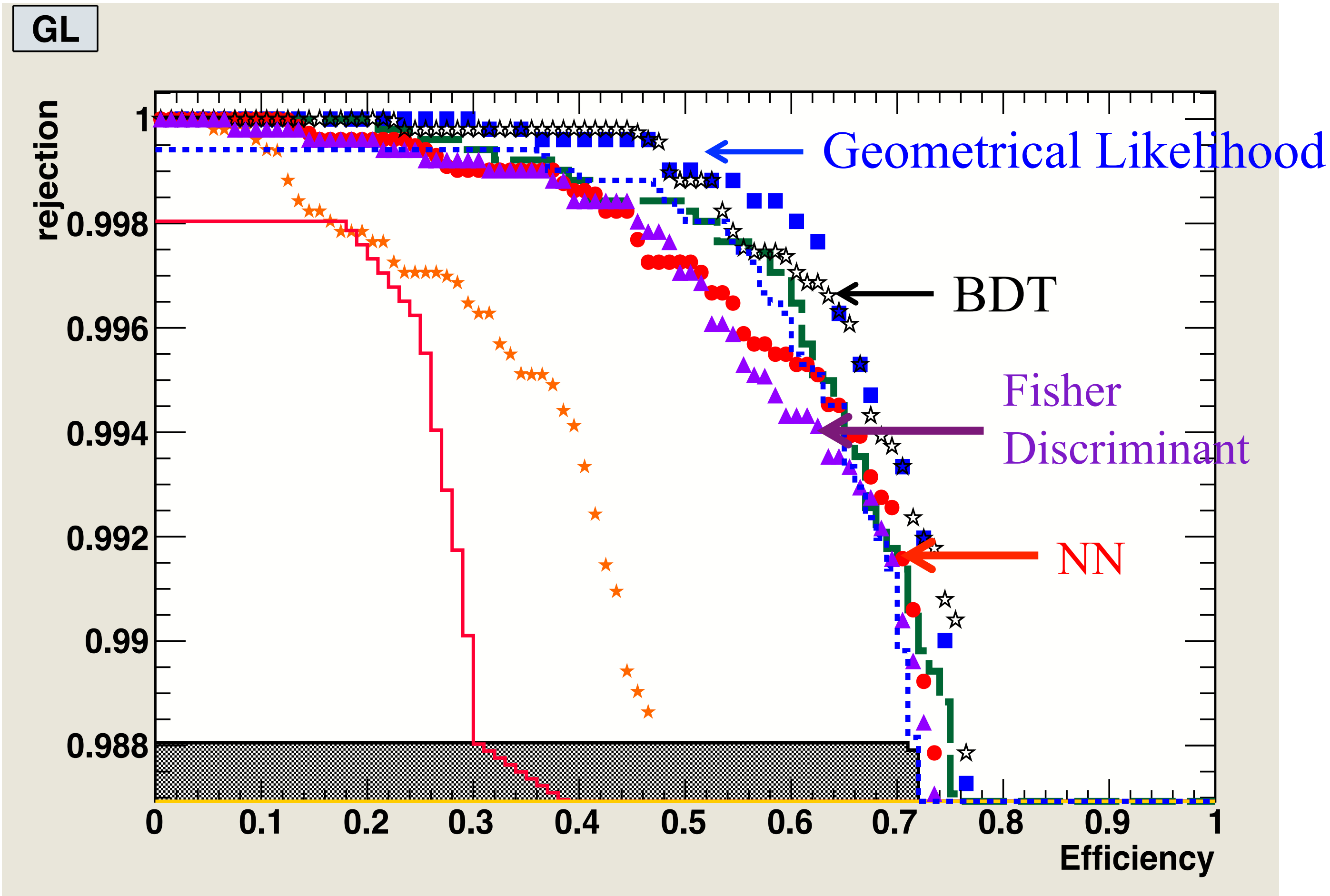


Variables are decorrelated and a Multi Variate Variable is built:
→ flat for signal
→ peaked at zero for background

Geometrical Likelihood (GL)

Comparison with other Multivariate Techniques
(with the same set of variables)

GL: Rejection vs Efficiency profile



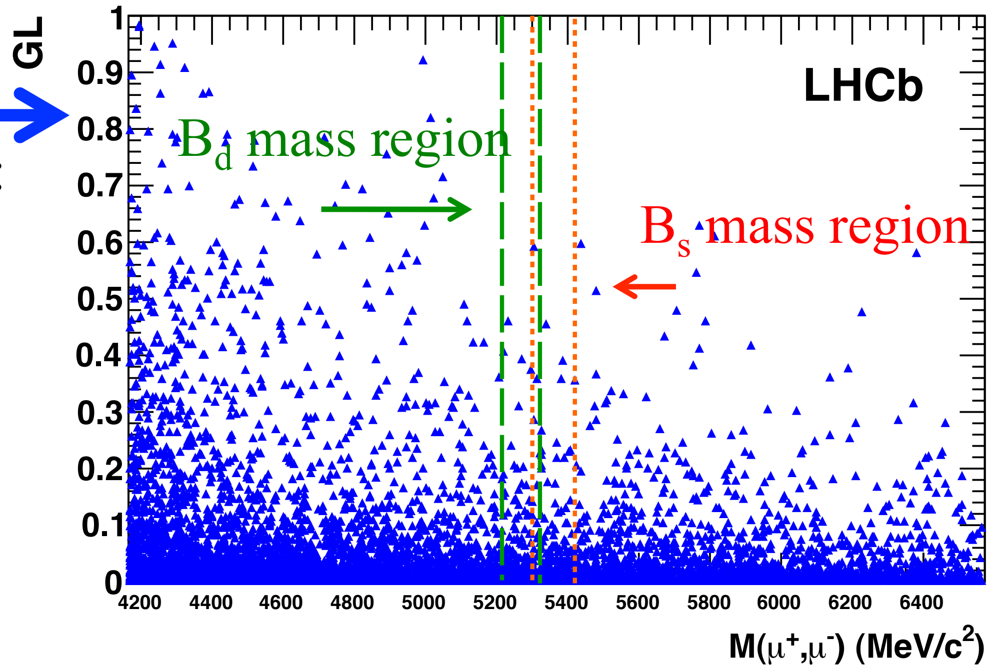
$B_{s,d} \rightarrow \mu\mu$ - Measure the BR/Upper limit: the CL_s binned method

Geometrical Likelihood vs Mass

1) Events are classified in 2D plane GL vs mass.

2) Signal regions are divided in bins: and for each bin the compatibility is computed with the:

- S+B hypothesis [CL_{S+B}]
- B only hypothesis [CL_B]



- $CL_S = CL_{S+B}/CL_B$ = compatibility with the signal hypothesis

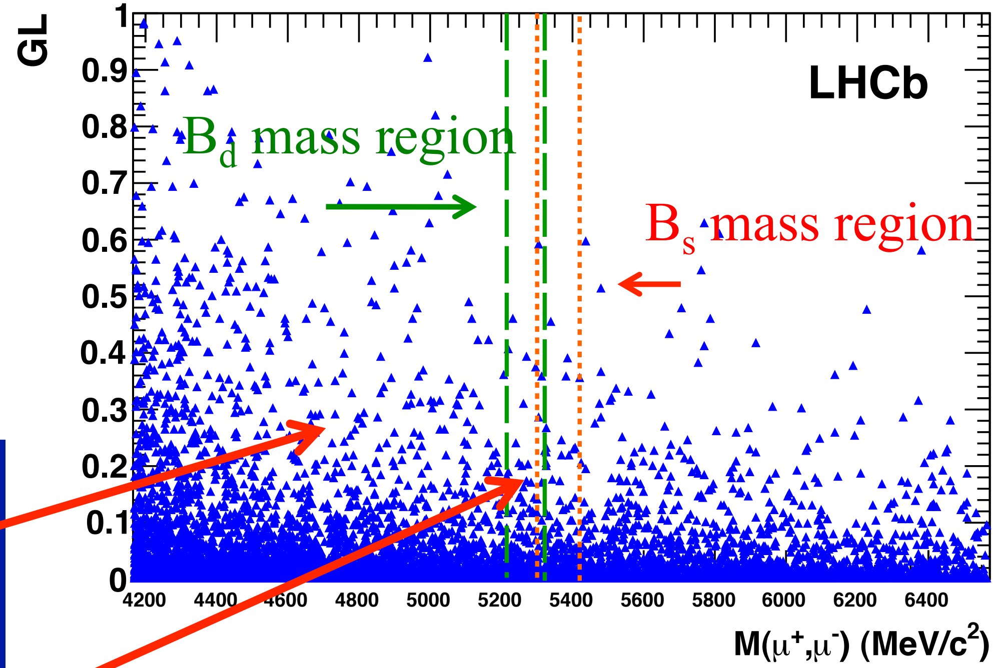
→Used to compute the exclusion

- CL_B = (in)compatibility with the background hypothesis

→ Used for observation

$B_{s,d} \rightarrow \mu\mu$ - Measure the BR/Upper limit: the CL_s binned method

Geometrical Likelihood vs Mass



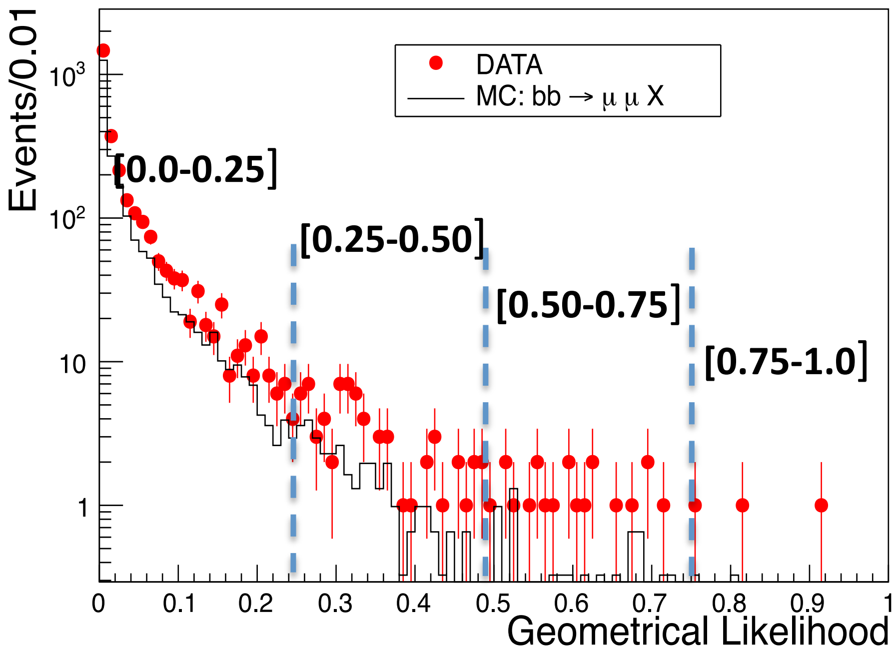
→ Expected background events:
- → Use mass sidebands

→ Expected signal events:
- → Need PDFs (Mass and GL) and an absolute normalization factor (for a given BR)

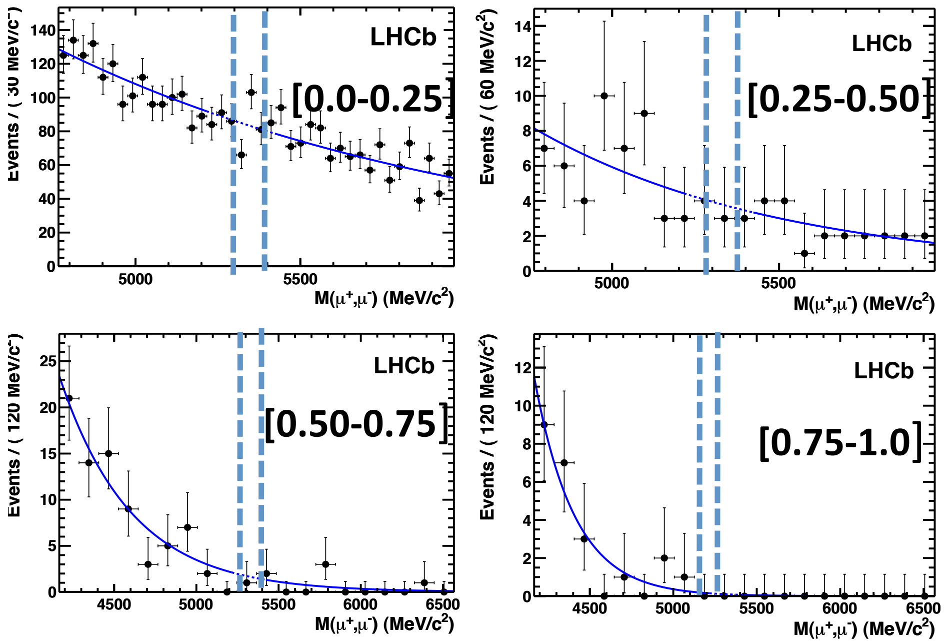
$B_{s,d} \rightarrow \mu\mu$: expected background in signal regions

The expected background events in signal regions are extracted from a fit of the mass sidebands divided in GL bins

Background GL in mass sidebands



Invariant mass in GL bins



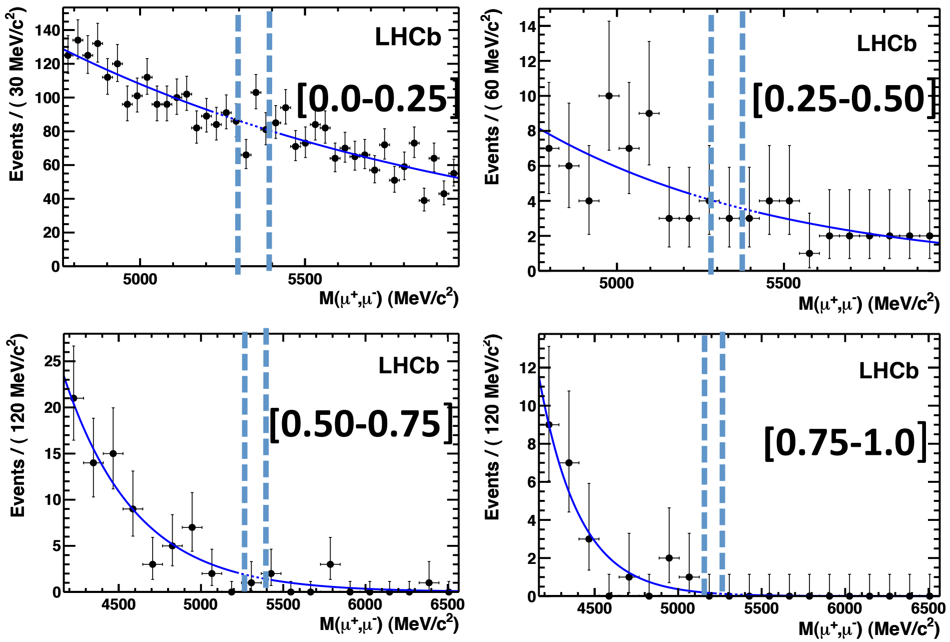
$B_{s,d} \rightarrow \mu\mu$: expected background in signal regions

The expected background events in signal regions are extracted from a fit of the mass sidebands divided in GL bins

Expected (observed) background events in $B_{s,d}$ mass regions

GL bin	$B_s \rightarrow \mu\mu$	$B_d \rightarrow \mu\mu$
0.0-0.25	329.1±6.4 (335)	351.6±6.6 (333)
0.25-0.50	7.4 ± 1 (7)	$8.3^{+1.1}_{-1.0}$ (8)
0.50-0.75	$1.51^{+0.41}_{-0.35}$ (1)	$1.85^{+0.45}_{-0.39}$ (1)
0.75-1.0	$0.08^{+0.10}_{-0.05}$ (0)	$0.13^{+0.13}_{-0.07}$ (0)

Invariant mass in GL bins



$B_{s,d} \to \mu\mu$: Signal Invariant Mass calibration

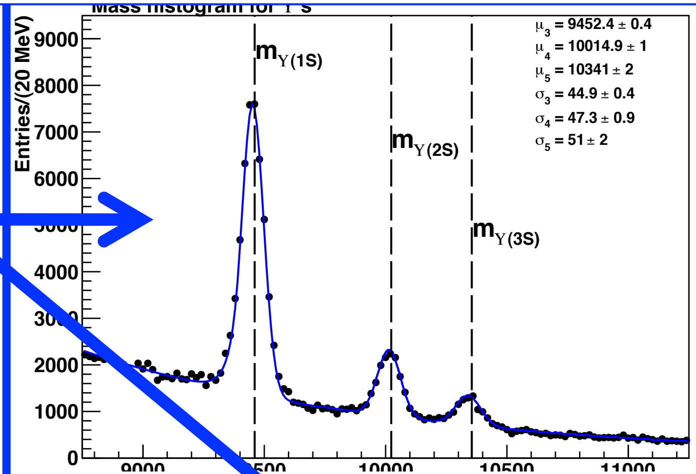
1) Mass average values $M(B_d)$, $M(B_s)$

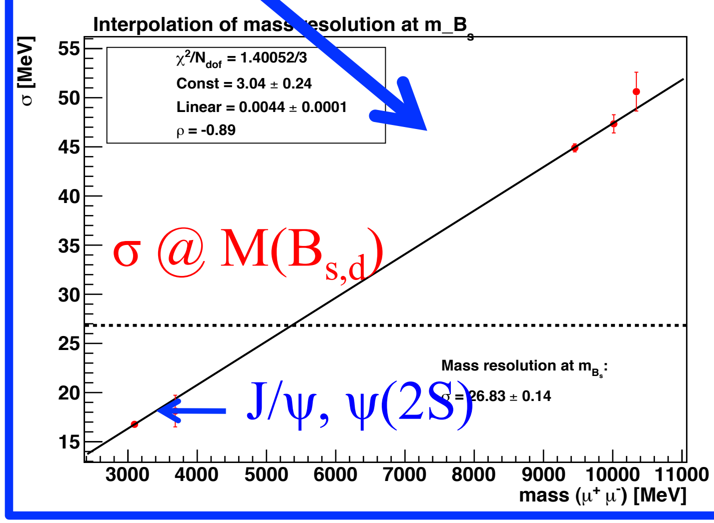
- from $B_d \to K\pi$ & $B_s \to KK$ samples

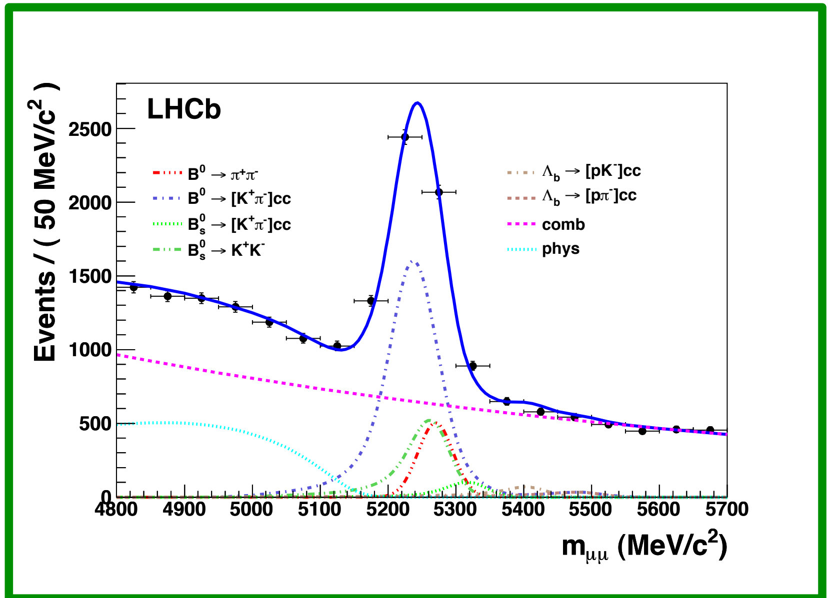
2) Mass resolutions $\sigma(M(B_{d,s}))$ from :

- $B \to hh'$ inclusive (noPID) sample:
- Interpolation from dimuon resonances

The Υ family: $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$







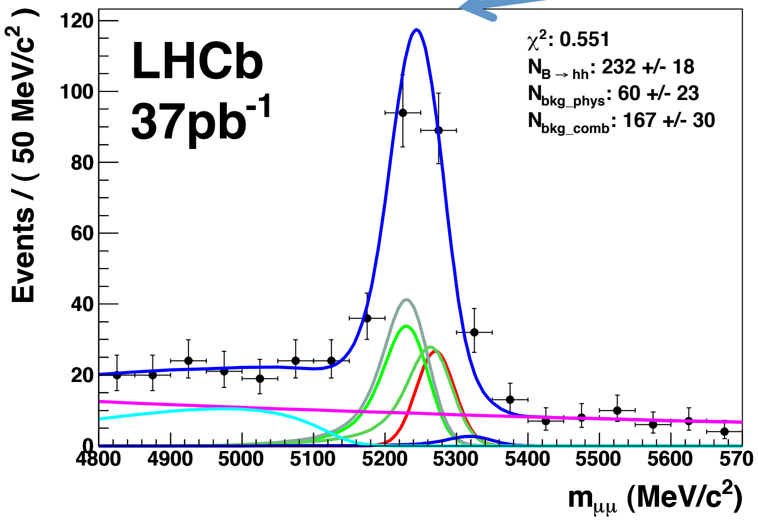
The two methods give compatible results:
$\sigma(M) = 26.7 \pm 0.9$ MeV/c^2

CDF (D0) : $\sigma(M) \sim 24$ (120) MeV/c^2

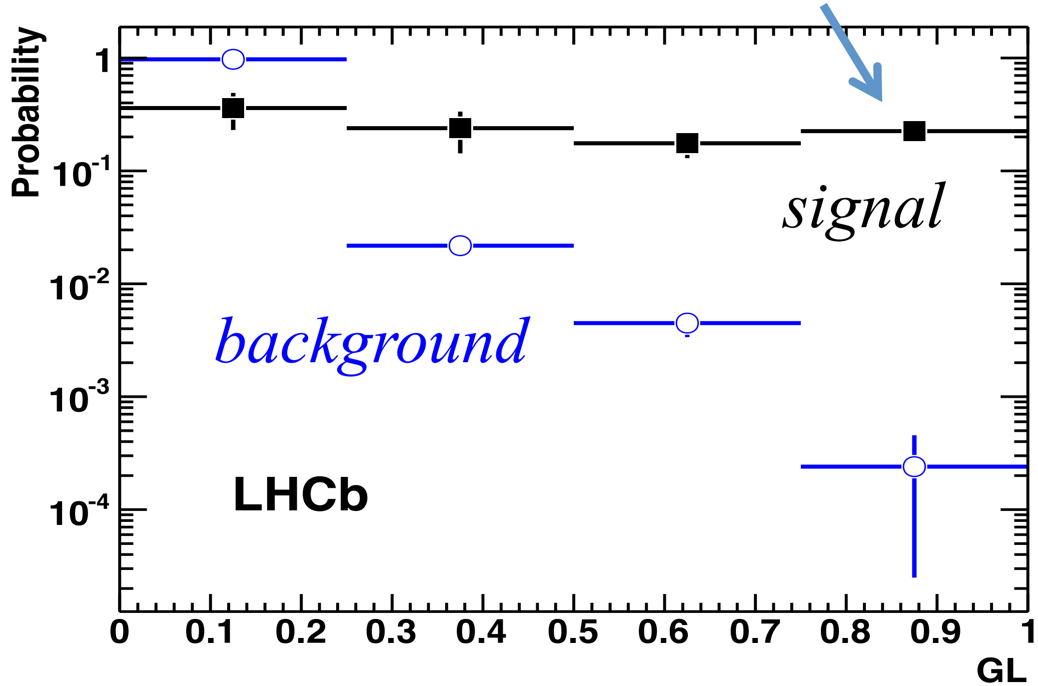
$B_{s,d} \rightarrow \mu\mu$: Geometrical Likelihood calibration

$B \rightarrow hh'$ sample is also used to calibrate the GL shape with data:
- identical topology
- use events triggered by the other b to avoid trigger bias

Ex: bin 4 [0.75-1.0]



The GL signal shape is given by the fractional yield of $B \rightarrow hh'$ in each GL bin.



GL shape for signal extracted from $B \rightarrow hh'$ is flat as expected.
Systematic error dominated by the fit model.

$B_{s,d} \rightarrow \mu\mu$: Normalization

- The signal PDFs can be translated into a number of expected signal events by normalizing to a channel with known BR

$$\boxed{\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{REC}}\,\epsilon_{\mathrm{cal}}^{\mathrm{SEL|REC}}\,\epsilon_{\mathrm{cal}}^{\mathrm{TRIG|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}}\,\epsilon_{\mathrm{sig}}^{\mathrm{SEL|REC}}\,\epsilon_{\mathrm{sig}}^{\mathrm{TRIG|SEL}}} \times \frac{f_{\mathrm{cal}}}{f_{B_s^0}} \times \frac{N_{B_s^0\to\mu^+\mu^-}}{N_{\mathrm{cal}}} = \alpha \times N_{B_s^0\to\mu^+\mu^-}}$$

Three different channels used:

1) $BR(B^+ \rightarrow J/\psi(\mu^+\mu^-)\, K^+) = (5.98\pm0.22)\, 10^{-5}$ 3.7% uncertainty

→ Similar trigger and PID. Tracking efficiency (+1 track) dominates the systematic in the ratio of efficiencies. Needs f_d/f_s as input: 13% uncertainty

2) $BR(B_s \rightarrow J/\psi(\mu^+\mu^-)\, \varphi(K^+K^-)) = (3.35\pm0.9)\, 10^{-5}$ 26% uncertainty

Similar trigger and PID. Tracking efficiency (+2 tracks) dominates the systematic

3) $BR(B^0 \rightarrow K^+\pi^-) = (1.94\pm0.06)\, 10^{-5}$ 3.1% uncertainty

Same topology in the final state. Different trigger dominate the syst. Needs f_d/f_s

Normalization Factors: breakdown

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{REC}}\,\epsilon_{\mathrm{cal}}^{\mathrm{SEL|REC}}\,\epsilon_{\mathrm{cal}}^{\mathrm{TRIG|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}}\,\epsilon_{\mathrm{sig}}^{\mathrm{SEL|REC}}\,\epsilon_{\mathrm{sig}}^{\mathrm{TRIG|SEL}}} \times \frac{f_{\mathrm{cal}}}{f_{B_s^0}} \times \frac{N_{B_s^0\to\mu^+\mu^-}}{N_{\mathrm{cal}}} = \alpha \times N_{B_s^0\to\mu^+\mu^-}$$

	$\mathcal{B}$ $(\times 10^{-5})$	$\frac{\epsilon_{\mathrm{norm}}^{\mathrm{REC}}\,\epsilon_{\mathrm{norm}}^{\mathrm{SEL\|REC}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}}\,\epsilon_{\mathrm{sig}}^{\mathrm{SEL\|REC}}}$	$\frac{\epsilon_{\mathrm{norm}}^{\mathrm{TRIG\|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{TRIG\|SEL}}}$	N_{norm}	$\alpha_{B_s^0\to\mu^+\mu^-}$ $(\times 10^{-9})$	$\alpha_{B^0\to\mu^+\mu^-}$ $(\times 10^{-9})$
$B^+ \to J/\psi K^+$	5.98 ± 0.22	0.49 ± 0.02	0.96 ± 0.05	12366 ± 403	8.4 ± 1.3	2.27 ± 0.18
$B_s^0 \to J/\psi\phi$	3.4 ± 0.9	0.25 ± 0.02	0.96 ± 0.05	760 ± 71	10.5 ± 2.9	2.83 ± 0.86
$B^0 \to K^+\pi^-$	1.94 ± 0.06	0.82 ± 0.06	0.072 ± 0.010	578 ± 74	7.3 ± 1.8	1.99 ± 0.40

CDF, 3.7 fb^{-1}, N($B^+ \to J/\psi$ K)~20000

We use **f_d/f_s=3.71±0.47**, a recent combination of LEP+Tevatron data by HFAG, with 13% uncertainty, dominated by LEP measurements

http://www.slac.stanford.edu/xorg/hfag/osc/end_2009/#FRAC

The normalization with three different channels is equivalent to perform three different analyses with different systematic uncertainties

Normalization Factors: breakdown

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

	$\mathcal{B}$ $(\times 10^{-5})$	$\frac{\epsilon^{\mathrm{REC}}_{\mathrm{norm}}\epsilon^{\mathrm{SEL\|REC}}_{\mathrm{norm}}}{\epsilon^{\mathrm{REC}}_{\mathrm{sig}}\epsilon^{\mathrm{SEL\|REC}}_{\mathrm{sig}}}$	$\frac{\epsilon^{\mathrm{TRIG\|SEL}}_{\mathrm{norm}}}{\epsilon^{\mathrm{TRIG\|SEL}}_{\mathrm{sig}}}$	N_{norm}	$\alpha_{B^0_s\to\mu^+\mu^-}$ $(\times 10^{-9})$	$\alpha_{B^0\to\mu^+\mu^-}$ $(\times 10^{-9})$
$B^+ \to J/\psi K^+$	5.98 ± 0.22	0.49 ± 0.02	0.96 ± 0.05	12366 ± 403	8.4 ± 1.3	2.27 ± 0.18
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$B^0 \to K^+\pi^-$	1.94 ± 0.06	0.82 ± 0.06	0.072 ± 0.010	578 ± 74	7.3 ± 1.8	1.99 ± 0.40

Ratio of trigger efficiencies for channels with J/ψ is close to 1

Ratio of reconstruction and selection efficiencies for $B^0 \to K\,\pi$ is ~82% (differences due different interaction probability with material)

Ratio of trigger efficiencies for $B^0 \to K\pi$ is low because $B \to K\pi$ is required to be triggered by the other b

Normalization: results

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{REC}} \epsilon_{\mathrm{cal}}^{\mathrm{SEL|REC}} \epsilon_{\mathrm{cal}}^{\mathrm{TRIG|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}} \epsilon_{\mathrm{sig}}^{\mathrm{SEL|REC}} \epsilon_{\mathrm{sig}}^{\mathrm{TRIG|SEL}}} \times \frac{f_{\mathrm{cal}}}{f_{B_s^0}} \times \frac{N_{B_s^0\to\mu^+\mu^-}}{N_{\mathrm{cal}}} = \alpha \times N_{B_s^0\to\mu^+\mu^-}$$

	$\mathcal{B}$ $(\times 10^{-5})$	$\frac{\epsilon_{\mathrm{norm}}^{\mathrm{REC}} \epsilon_{\mathrm{norm}}^{\mathrm{SEL\|REC}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}} \epsilon_{\mathrm{sig}}^{\mathrm{SEL\|REC}}}$	$\frac{\epsilon_{\mathrm{norm}}^{\mathrm{TRIG\|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{TRIG\|SEL}}}$	N_{norm}	$\alpha_{B_s^0\to\mu^+\mu^-}$ $(\times 10^{-9})$	$\alpha_{B^0\to\mu^+\mu^-}$ $(\times 10^{-9})$
$B^+ \to J/\psi K^+$	5.98 ± 0.22	0.49 ± 0.02	0.96 ± 0.05	12366 ± 403	8.4 ± 1.3	2.27 ± 0.18
$B_s^0 \to J/\psi \phi$	3.4 ± 0.9	0.25 ± 0.02	0.96 ± 0.05	760 ± 71	10.5 ± 2.9	2.83 ± 0.86
$B^0 \to K^+\pi^-$	1.94 ± 0.06	0.82 ± 0.06	0.072 ± 0.010	578 ± 74	7.3 ± 1.8	1.99 ± 0.40

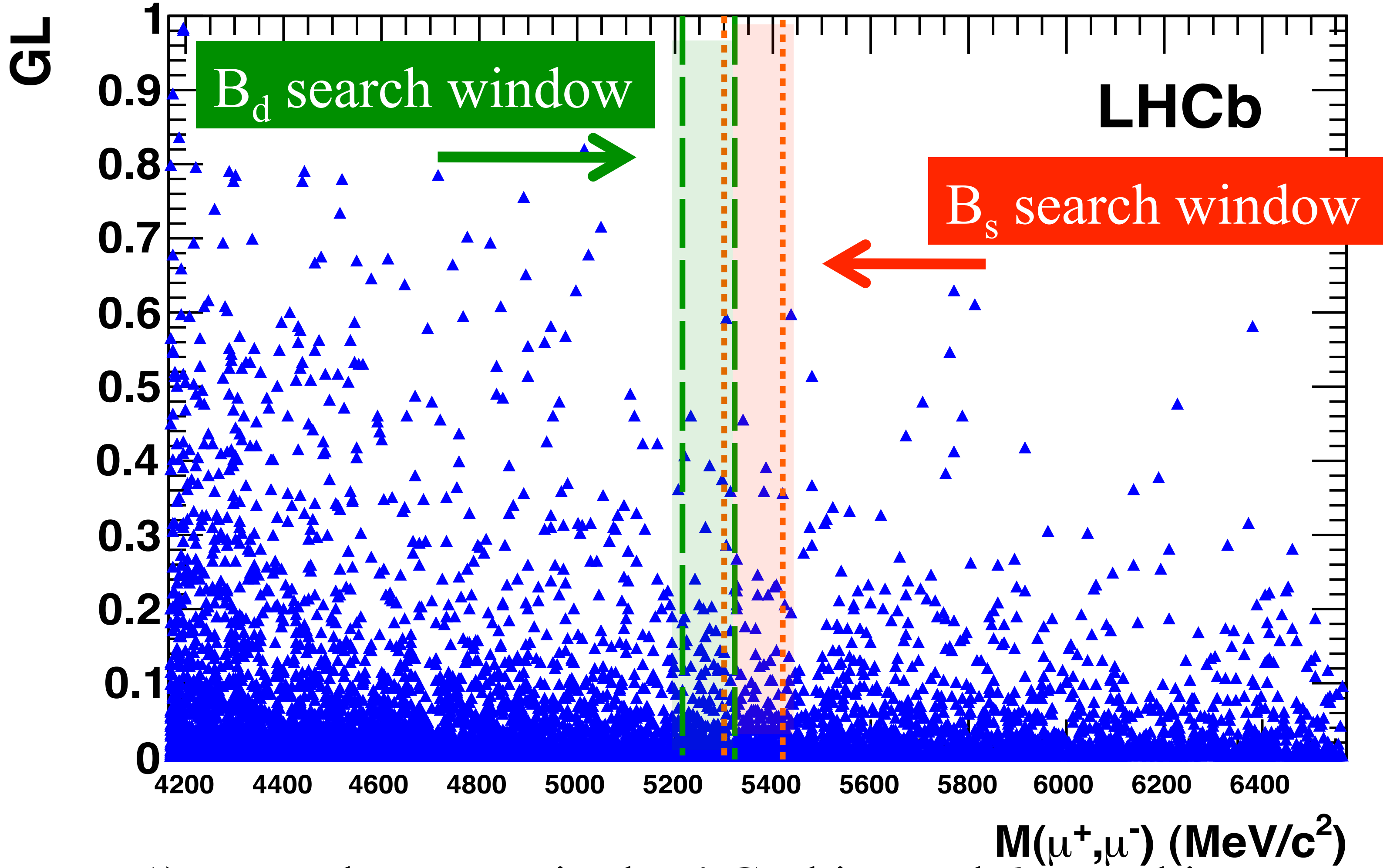
The three normalization channels give compatible results:

→ Weighted average accounting for correlated systematic uncertainties

$$\alpha_{B_s^0\to\mu^+\mu^-} = (8.6 \pm 1.1) \times 10^{-9}$$

$$\alpha_{B^0\to\mu^+\mu^-} = (2.24 \pm 0.16) \times 10^{-9}$$

Look inside the box….



1) count the events in the 4 GL bins and 6 mass bins,
2) compare observed events with the expected number of signal and background events

$B_s \rightarrow \mu\mu$ search window

Invariant Mass bins (MeV/c^2)		Geometrical Likelihood Bins [0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
[−60, −40]	Exp. bkg.	$56.9^{+1.1}_{-1.1}$	$1.31^{+0.19}_{-0.17}$	$0.282^{+0.076}_{-0.065}$	$0.016^{+0.021}_{-0.010}$
	Exp. sig.	$0.0076^{+0.0034}_{-0.0030}$	$0.0050^{+0.0027}_{-0.0020}$	$0.0037^{+0.0015}_{-0.0011}$	$0.0047^{+0.0015}_{-0.0010}$
	Observed	39	2	1	0
[−40, −20]	Exp. bkg.	$56.1^{+1.1}_{-1.1}$	$1.28^{+0.18}_{-0.17}$	$0.269^{+0.072}_{-0.062}$	$0.015^{+0.020}_{-0.009}$
	Exp. sig.	$0.0220^{+0.0084}_{-0.0079}$	$0.0146^{+0.0066}_{-0.0053}$	$0.0107^{+0.0036}_{-0.0026}$	$0.0138^{+0.0034}_{-0.0024}$
	Observed	55	2	0	0
[−20, 0]	Exp. bkg.	$55.3^{+1.1}_{-1.1}$	$1.24^{+0.17}_{-0.16}$	$0.257^{+0.069}_{-0.059}$	$0.014^{+0.018}_{-0.009}$
	Exp. sig.	$0.038^{+0.015}_{-0.014}$	$0.025^{+0.012}_{-0.010}$	$0.0183^{+0.0063}_{-0.0047}$	$0.0235^{+0.0059}_{-0.0042}$
	Observed	73	0	0	0
[0, 20]	Exp. bkg.	$54.4^{+1.1}_{-1.1}$	$1.21^{+0.17}_{-0.16}$	$0.246^{+0.066}_{-0.057}$	$0.013^{+0.017}_{-0.008}$
	Exp. sig.	$0.03761^{+0.015}_{-0.015}$	$0.025^{+0.012}_{-0.010}$	$0.0183^{+0.0063}_{-0.0047}$	$0.0235^{+0.0060}_{-0.0044}$
	Observed	60	0	0	0
[20, 40]	Exp. bkg.	$53.6^{+1.1}_{-1.0}$	$1.18^{+0.17}_{-0.15}$	$0.235^{+0.063}_{-0.054}$	$0.012^{+0.015}_{-0.007}$
	Exp. sig.	$0.0220^{+0.0084}_{-0.0081}$	$0.0146^{+0.0067}_{-0.0054}$	$0.0107^{+0.0036}_{-0.0027}$	$0.0138^{+0.0035}_{-0.0025}$
	Observed	53	2	0	0
[40, 60]	Exp. bkg.	$52.8^{+1.0}_{-1.0}$	$1.15^{+0.16}_{-0.15}$	$0.224^{+0.060}_{-0.052}$	$0.011^{+0.014}_{-0.007}$
	Exp. sig.	$0.0076^{+0.0031}_{-0.0027}$	$0.0050^{+0.0025}_{-0.0019}$	$0.0037^{+0.0013}_{-0.0010}$	$0.0047^{+0.0013}_{-0.0010}$
	Observed	55	1	0	0

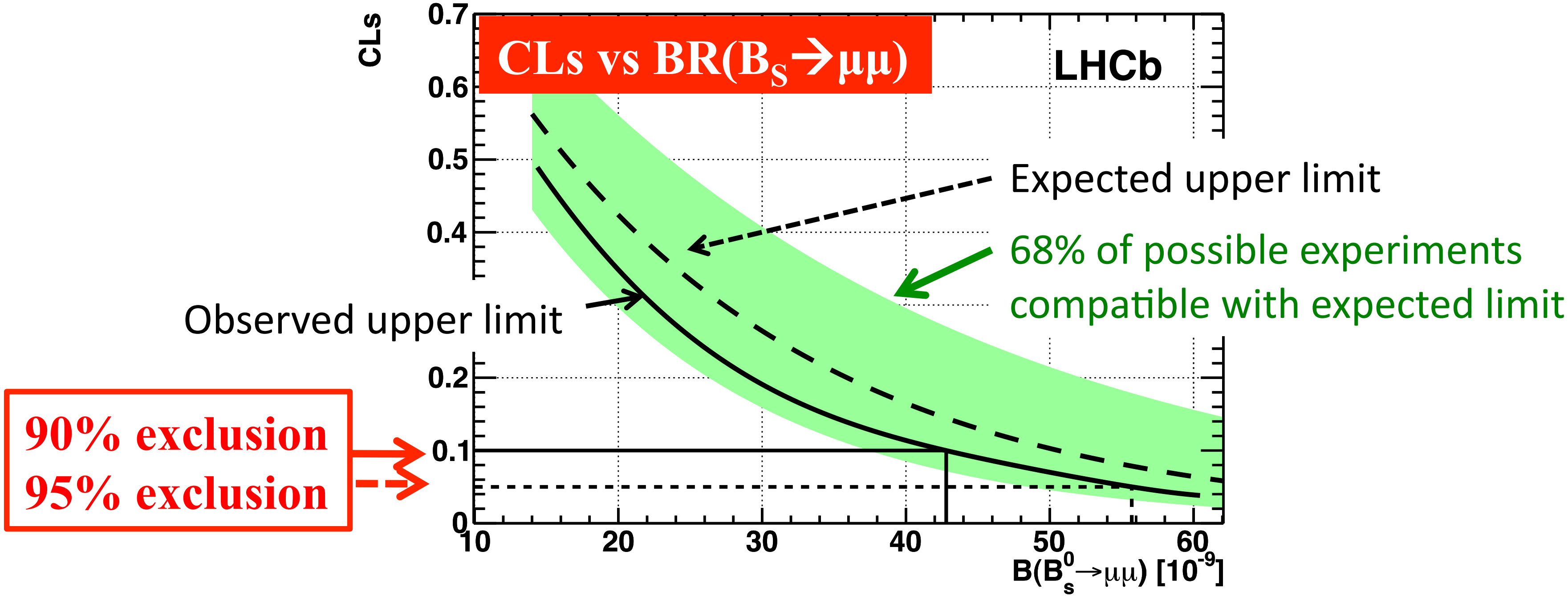
$B_d \rightarrow \mu\mu$ search window

Geometrical Likelihood Bins

Invariant Mass bins (MeV/c^2)		[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
[−60, −40]	Exp. bkg.	$60.8^{+1.2}_{-1.1}$	$1.48^{+0.19}_{-0.18}$	$0.345^{+0.084}_{-0.073}$	$0.024^{+0.027}_{-0.014}$
	Exp. sig.	$0.0009^{+0.0004}_{-0.0003}$	$0.0006^{+0.0003}_{-0.0002}$	$0.0004^{+0.0002}_{-0.0001}$	$0.0006^{+0.0002}_{-0.0001}$
	Observed	59	2	0	0
[−40, −20]	Exp. bkg.	$59.9^{+1.1}_{-1.1}$	$1.44^{+0.19}_{-0.17}$	$0.329^{+0.080}_{-0.070}$	$0.022^{+0.024}_{-0.013}$
	Exp. sig.	$0.0026^{+0.009}_{-0.009}$	$0.0017^{+0.0008}_{-0.0006}$	$0.0013^{+0.0004}_{-0.0003}$	$0.0016^{+0.0004}_{-0.0002}$
	Observed	67	0	0	0
[−20, 0]	Exp. bkg.	$59.0^{+1.1}_{-1.1}$	$1.40^{+0.18}_{-0.17}$	$0.315^{+0.077}_{-0.067}$	$0.020^{+0.022}_{-0.012}$
	Exp. sig.	$0.0045^{+0.0017}_{-0.0017}$	$0.0030^{+0.0014}_{-0.0011}$	$0.00219^{+0.00067}_{-0.00054}$	$0.00280^{+0.00060}_{-0.00045}$
	Observed	56	2	0	0
[0, 20]	Exp. bkg.	$58.1^{+1.1}_{-1.1}$	$1.36^{+0.18}_{-0.16}$	$0.300^{+0.073}_{-0.064}$	$0.019^{+0.021}_{-0.011}$
	Exp. sig.	$0.0045^{+0.0017}_{-0.0017}$	$0.0030^{+0.0014}_{-0.0011}$	$0.00219^{+0.00067}_{-0.00054}$	$0.00280^{+0.00060}_{-0.00045}$
	Observed	60	0	0	0
[20, 40]	Exp. bkg.	$57.3^{+1.1}_{-1.1}$	$1.33^{+0.17}_{-0.16}$	$0.287^{+0.070}_{-0.061}$	$0.017^{+0.019}_{-0.010}$
	Exp. sig.	$0.0026^{+0.0009}_{-0.0009}$	$0.0017^{+0.0008}_{-0.0006}$	$0.0013^{+0.0004}_{-0.0003}$	$0.0016^{+0.0004}_{-0.0002}$
	Observed	42	2	1	0
[40, 60]	Exp. bkg.	$56.4^{+1.1}_{-1.1}$	$1.29^{+0.17}_{-0.16}$	$0.274^{+0.067}_{-0.058}$	$0.016^{+0.018}_{-0.009}$
	Exp. sig.	$0.0009^{+0.0003}_{-0.0003}$	$0.0006^{+0.0003}_{-0.0002}$	$0.0004^{+0.0001}_{-0.0001}$	$0.0006^{+0.0002}_{-0.0001}$
	Observed	49	2	0	0

Results: $B_s \rightarrow \mu\mu$

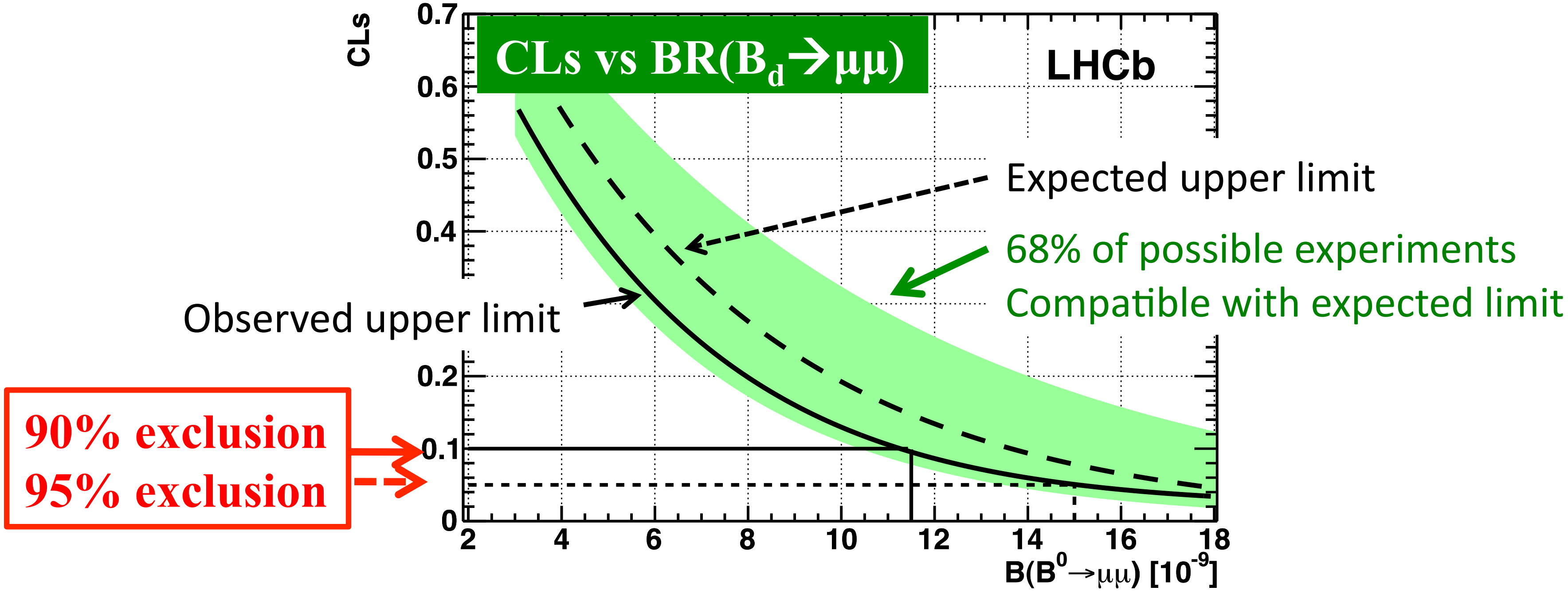
[submitted to Phys.Lett.B, arXiv:1103.2465]



		@ 90% CL	@ 95% CL
LHCb	Observed (expected), **37 pb^{-1}**	**< 43** (51) **x10^{-9}**	**< 56** (65) **x10^{-9}**
D0	World best published, **6.1 fb^{-1}** PLB 693 539 (2010)	**< 42 x10^{-9}**	**< 51 x10^{-9}**
CDF	Preliminary, **3.7 fb^{-1}** Note 9892	**< 36 x10^{-9}**	**< 43 x 10^{-9}**

Results: $B^0_d \rightarrow \mu\mu$

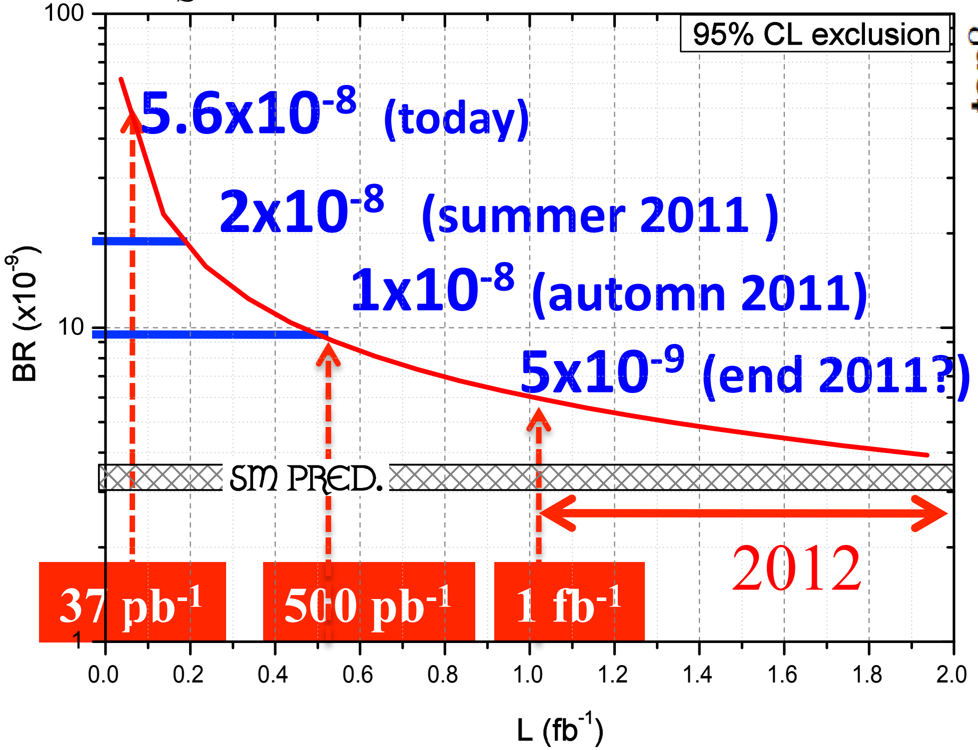
[submitted to Phys.Lett.B, arXiv:1103.2465]



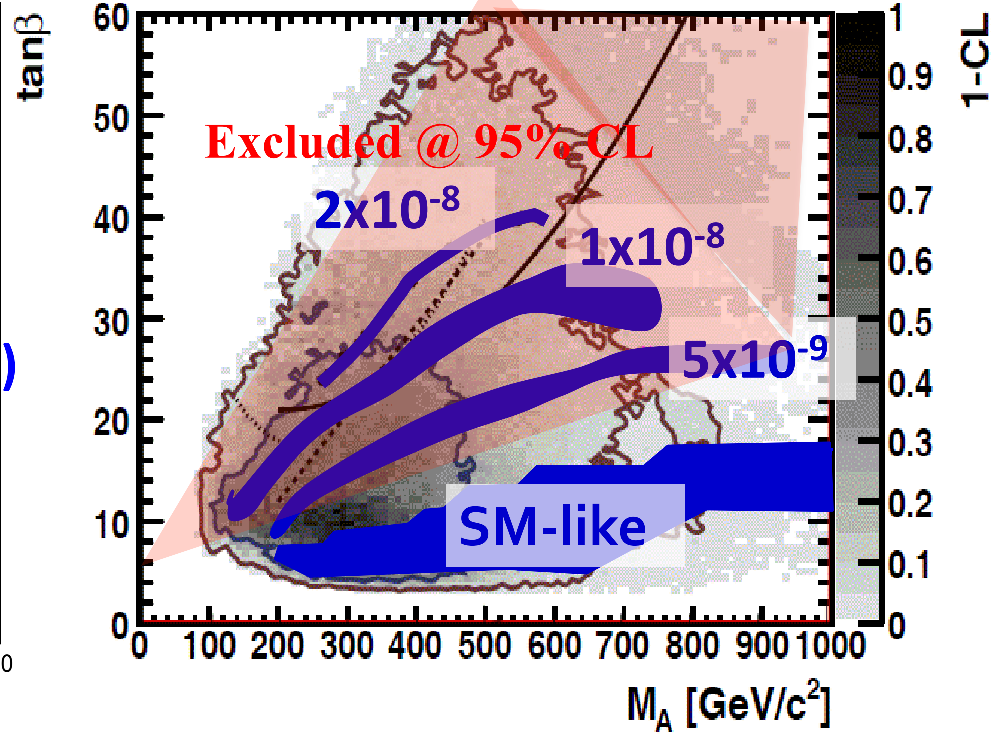
		@ 90% CL	@ 95% CL
LHCb	Observed (expected) **37 pb^{-1}**	**< 12 (14) x10^{-9}**	**< 15 (18) x10^{-9}**
CDF	World best, **2 fb^{-1}** PRL 100 101802 (2008)	**< 15 x10^{-9}**	**< 18 x10^{-9}**
CDF	Preliminary, **3.7 fb^{-1}** Note 9892	**< 7.6 x10^{-9}**	**< 9.1 x 10^{-9}**

$B_s \rightarrow \mu\mu$: LHCb reach in 2011-2012

$B_S \rightarrow \mu\mu$ exclusion @ 95% CL

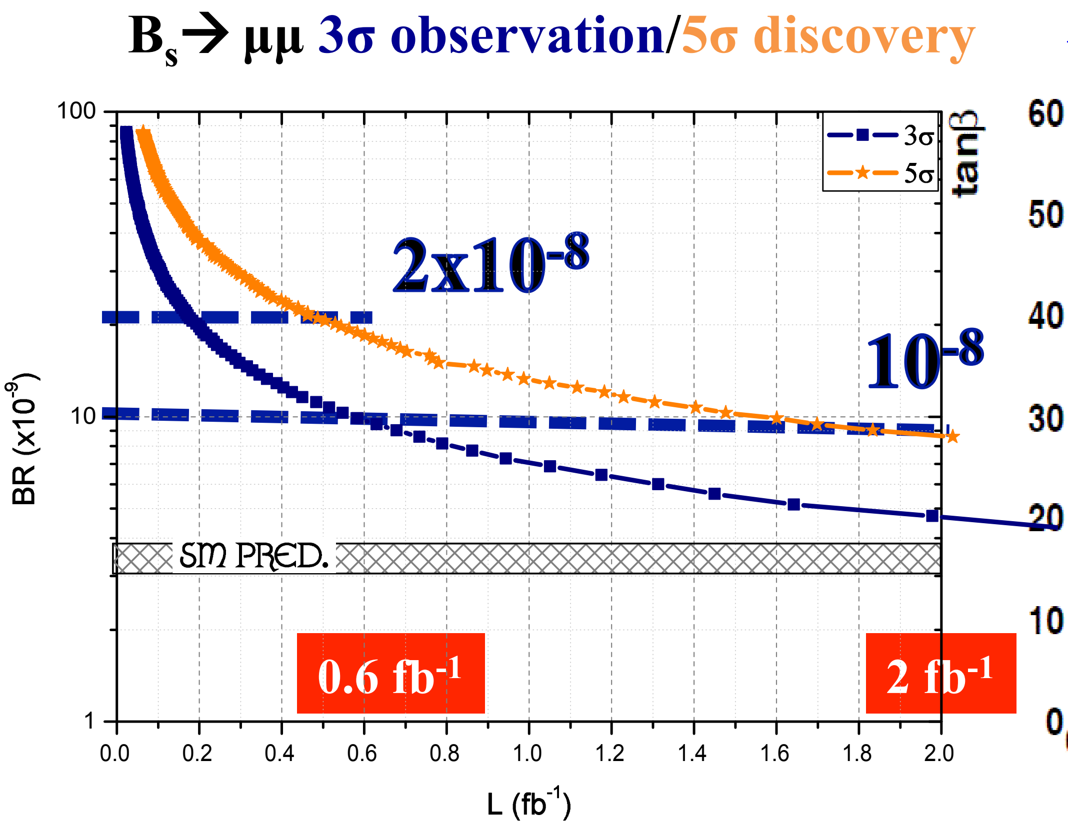


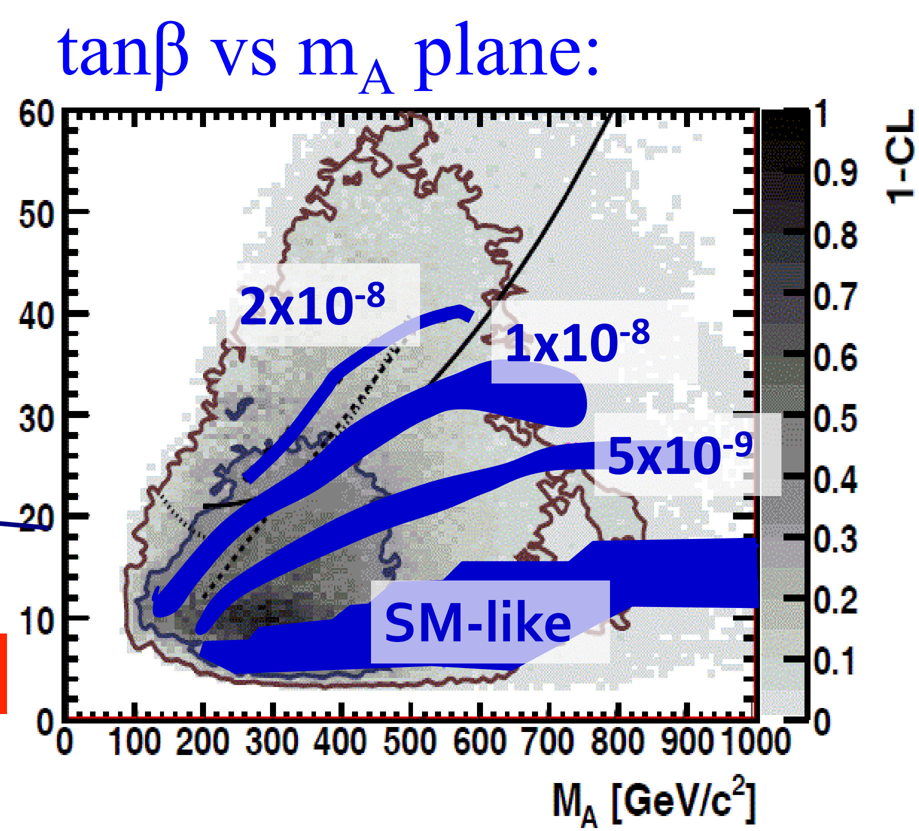
tanβ vs m_A plane:



With the data collected in 2011-2012 we will be able to explore the very interesting region down to SM value

$B_s \rightarrow \mu\mu$: LHCb reach in 2011-2012





With the data collected in 2011-2012 we will be able to have a 5σ discovery if BR>10^{-8}
[LHCb with 2 fb^{-1} equivalent to CMS with 30-60 fb^{-1}]

Where to look for NP signals @ LHCb?

The editor's choice

- NP contributions in Rare decays:
  1) BR($B_{s,d} \rightarrow \mu\mu$), $D^0 \rightarrow \mu\mu$
  2) forward-backward asymmetry in $B_d \rightarrow K^*\mu\mu$
  3) non-SM photon polarization in exclusive $b \rightarrow s\gamma$ decays

Very close to the 2010 final number: all Intermediate results presented in La Thuile 10 days ago

-NP contributions in CP violating decays:

1) in box diagrams :

- **B_s mixing phase with $B_s \rightarrow J/\psi\varphi$** (and $B_s \rightarrow J/\psi\ f_0$)
- CP phase in D mixing

2) penguin diagrams:

Compare two measurements of a given CP asymmetry, in processes with and without penguins
→any discrepancy is sign of New Physics

- $\sin(2\beta)$ from $B^0 \rightarrow J/\psi K_S$ and $\sin(2\beta)$ from $B^0 \rightarrow \phi K_S$
- γ from $B_{(s)} \rightarrow D_{(s)}K$ and γ from $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$
- betas from $B_s \rightarrow J/\psi\varphi$ (f_0) and $B_s \rightarrow \varphi\varphi$

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-LFV decays with muons in the final state: eg $\tau \rightarrow \mu\mu\mu$

CPV in B_s mixing: …the (still) unresolved saga…

- The observable weak phase is: $\Phi = \Phi^{SM} + \Phi^{NP}$

- In the Standard Model is small…..

$$\Phi^{SM}(Bs \rightarrow J/\psi\,\phi) = 2\arg(V_{ts}{}^{*}\,V_{tb}) - 2\arg(V_{cs}{}^{*}\,V_{cb}) = -2\,\beta s \cong o\,(\lambda^2)$$

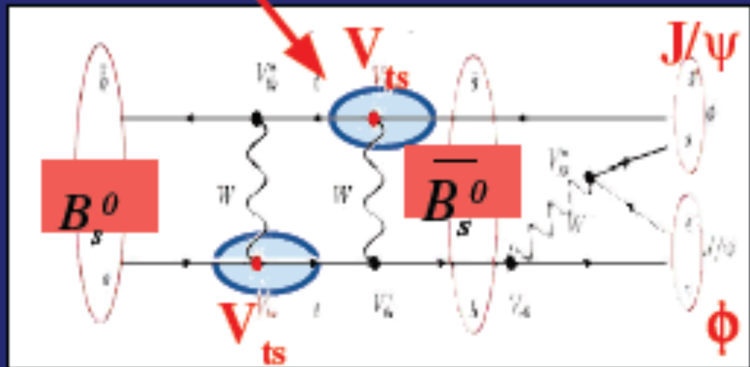
$$V_{CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho+i\eta)] & \boxed{-A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\rho+i\eta)]} & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

…. and well known:

$$\Phi^{SM}(Bs \rightarrow J/\psi\,\phi) = -2\,\beta s = -0.0368 \pm 0.0017 \text{ (CKMFitter, summer07)}$$

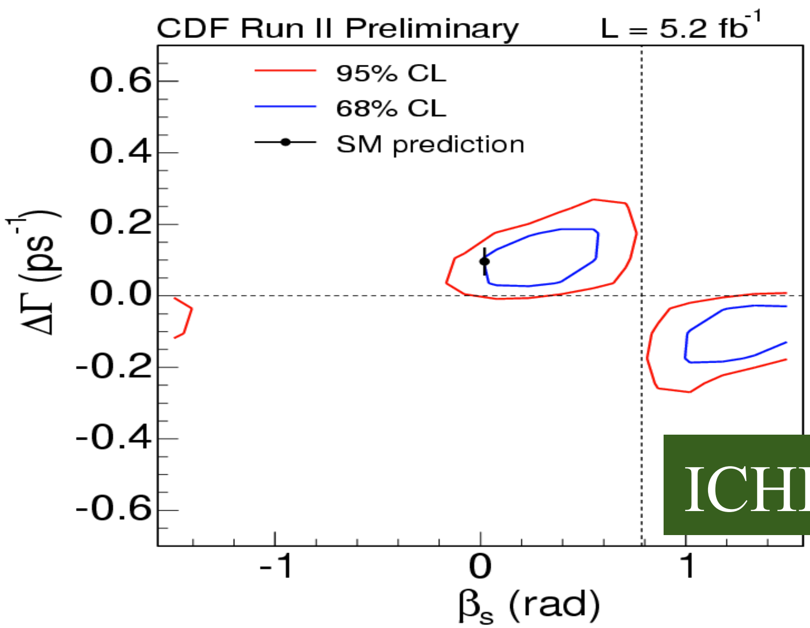
- In presence of New Physics:

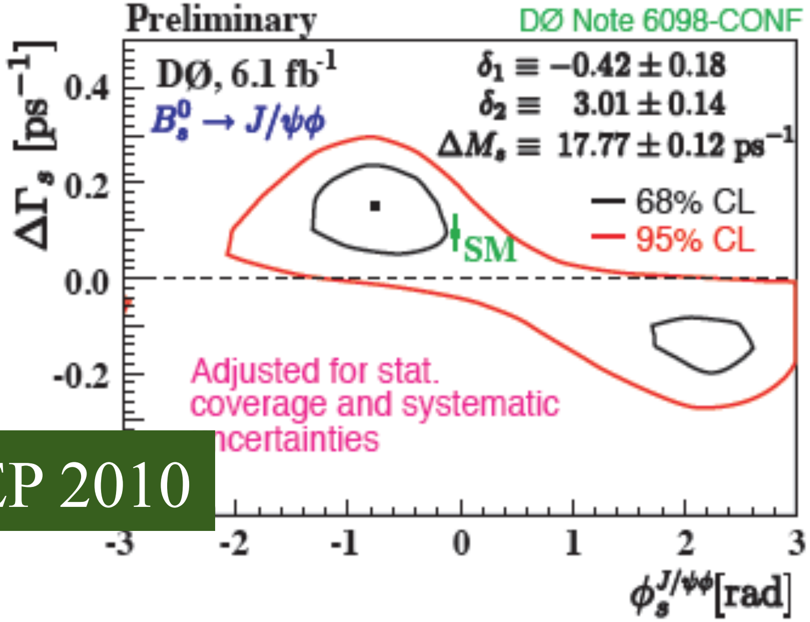
$$\Phi(Bs \rightarrow J/\psi\,\phi) = -2\beta s + \Phi^{NP}{}_{M}$$



CPV in B_s mixing:
…the (still) unresolved saga…

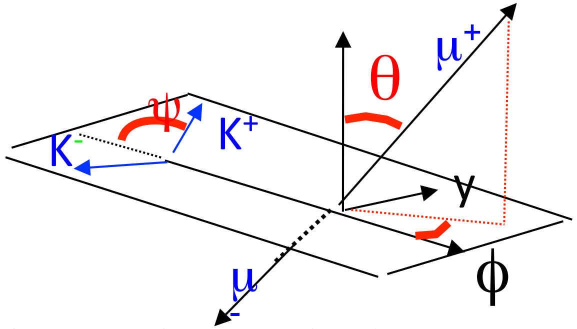
- The weak phase of B_s mixing is presently under investigation at Tevatron via the time-dependent study of the $B_s \rightarrow J/\psi\varphi$ decay [$A_{\psi\varphi}$] & via the semileptonic charge asymmetry [a_{sl}] (same-sign muons).
- Several new results in 2010: a_{sl} by D0 [~3σ deviation from SM] + update $A_{\psi\varphi}$ by both CDF and D0 [agreement with SM at ~1σ]





ICHEP 2010

B_s mixing phase in $B_s \rightarrow J/\psi\ \varphi$



The channel is complex ($P \rightarrow VV$)….

two particles [B_s,$B_s$bar] decaying in 3 final states [2 CP-even, 1 CP-odd]:

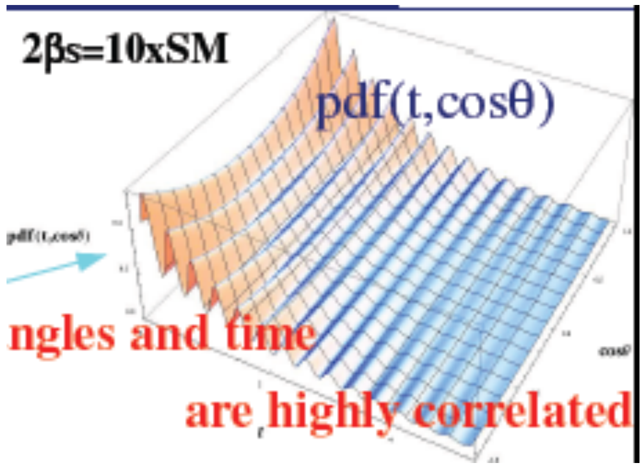
→ initial states must be tagged

→ final states need to be statistically separated through angular analysis

… and the extraction of the phase experimentally very challenging:

Most critical parameters are mistag and proper time resolution

$\Rightarrow$ sensitivity on $2\beta_s$ goes as $\sim (1\text{-}2\omega)^2 \exp(-\Delta m_s^{\,2}\sigma^2(\tau)/2)$



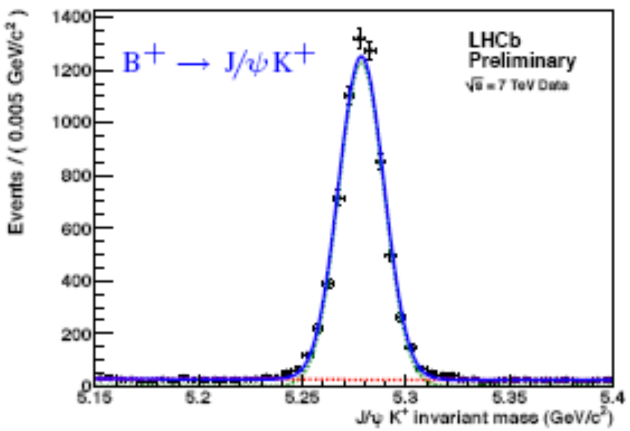
$B_s \to J/\psi\varphi$ analysis ingredients

- Trigger and select signals and control channels w/o distorting proper time (and angular) distributions
  - proof: measure lifetimes of b-hadron $\to J/\psi X$
- Disentangle polarizations of $P \to VV$ decays
  - proof: measure polarization parameters in $B_d \to J/\psi K^*$
- Determine initial flavour of B mesons
  - proof: measure Δm_d and Δm_s
- Fit differential rates of initial B_s and $\overline{B}_s$
  - first step: untagged analysis of $B_s \to J/\psi\varphi$

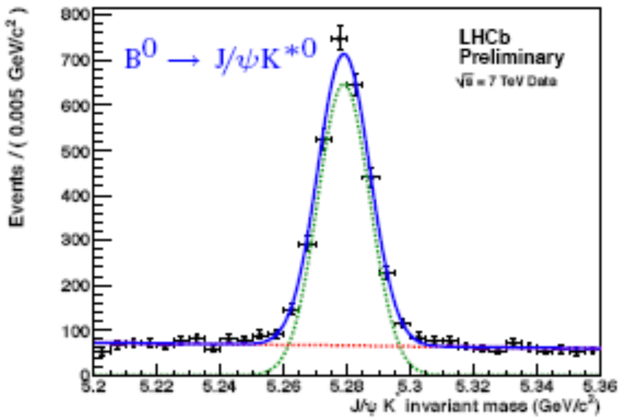
Selection of b→J/ψX

- Trigger and selection: avoid distortion of proper time distributions (no cuts on impact parameters)
- Retain prompt background events (t~0) for time resolution calibration: $\sigma_t \sim 50$ fs
- Excellent mass resolutions
- Very low background with t>0.3 ps, shown below:

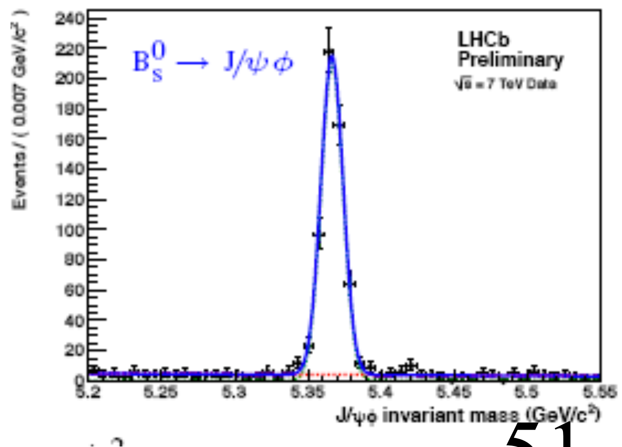
$\sigma_m = 10.7\ \mathrm{MeV}/c^2$



$\sigma_m = 8\ \mathrm{MeV}/c^2$

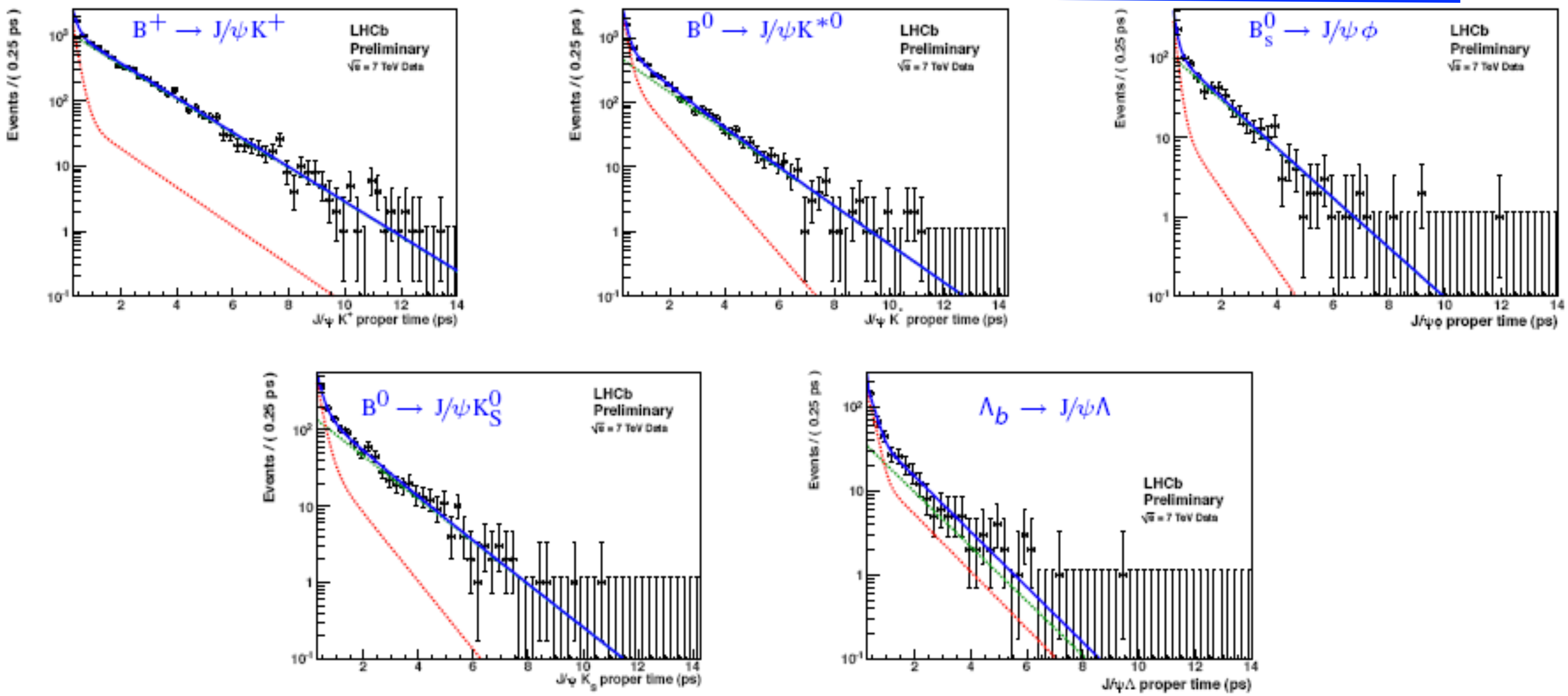


$\sigma_m = 7\ \mathrm{MeV}/c^2$



Here the full detector is at work: trigger, mass resolution, vertex capability, PID

b→J/ψX lifetimes (LHCb-CONF-2011-001)

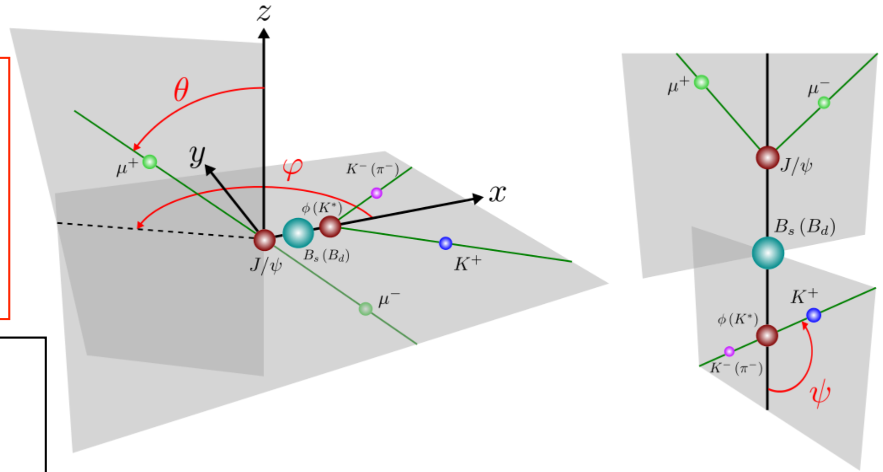


Channel	LHCb yield	LHCb "lifetime"(*) stat. and sys. (ps)	PDG (ps)
$B^+ \to J/\psi K^+$	6741 ± 85	$1.689 \pm 0.022 \pm 0.047$	1.638 ± 0.011
$B^0 \to J/\psi K^{*0}$	2668 ± 58	$1.512 \pm 0.032 \pm 0.042$	1.525 ± 0.009
$B^0 \to J/\psi K_S^0$	838 ± 31	$1.558 \pm 0.056 \pm 0.022$	1.525 ± 0.009
$B_s^0 \to J/\psi \phi$	570 ± 24	$1.447 \pm 0.064 \pm 0.056$	1.477 ± 0.046
$\Lambda_b \to J/\psi \Lambda$	187 ± 16	$1.353 \pm 0.108 \pm 0.035$	$1.391^{+0.038}_{-0.037}$

* *All "lifetimes" are measured with a single exponential*

Angular analysis of $B_d \to J/\psi K^*$
(LHCb-CONF-2011-002)

- P→VV polarization amplitudes (A_0, $A_{||}$, $A_\perp$) can be measured in distribution of transversity angles (θ, φ,ψ)
- Correct for angular efficiency using simulation
- Kπ S-wave included

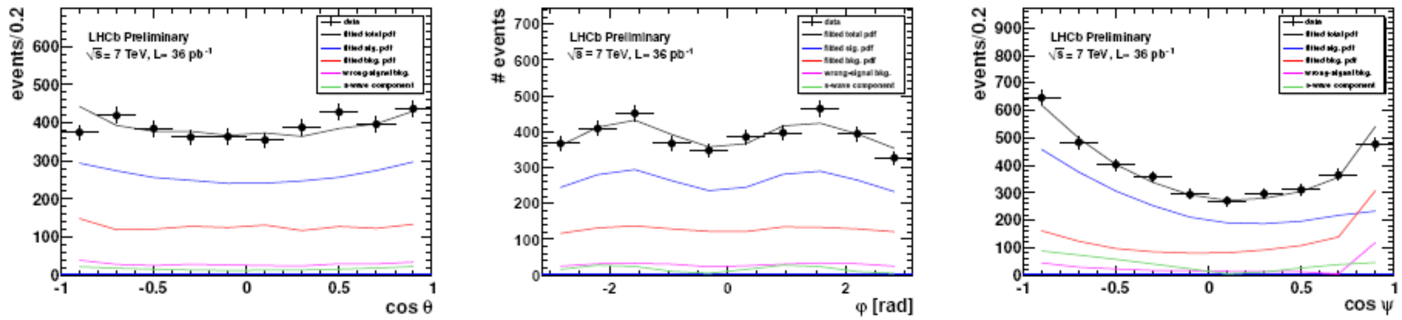


LHCb preliminary

$$|A_{||}|^2 = 0.252 \pm 0.020 \pm 0.016$$
$$|A_\perp|^2 = 0.178 \pm 0.020 \pm 0.017$$
$$\delta_{||}\,(\mathrm{rad}) = -2.87 \pm 0.11 \pm 0.10$$
$$\delta_\perp\,(\mathrm{rad}) = 3.02 \pm 0.10 \pm 0.07$$

Babar, PRD 76, 031002

$$|A_{||}|^2 = 0.211 \pm 0.010 \pm 0.006$$
$$|A_\perp|^2 = 0.233 \pm 0.010 \pm 0.005$$
$$\delta_{||}\,(\mathrm{rad}) = -2.93 \pm 0.08 \pm 0.04$$
$$\delta_\perp\,(\mathrm{rad}) = 2.91 \pm 0.05 \pm 0.03$$

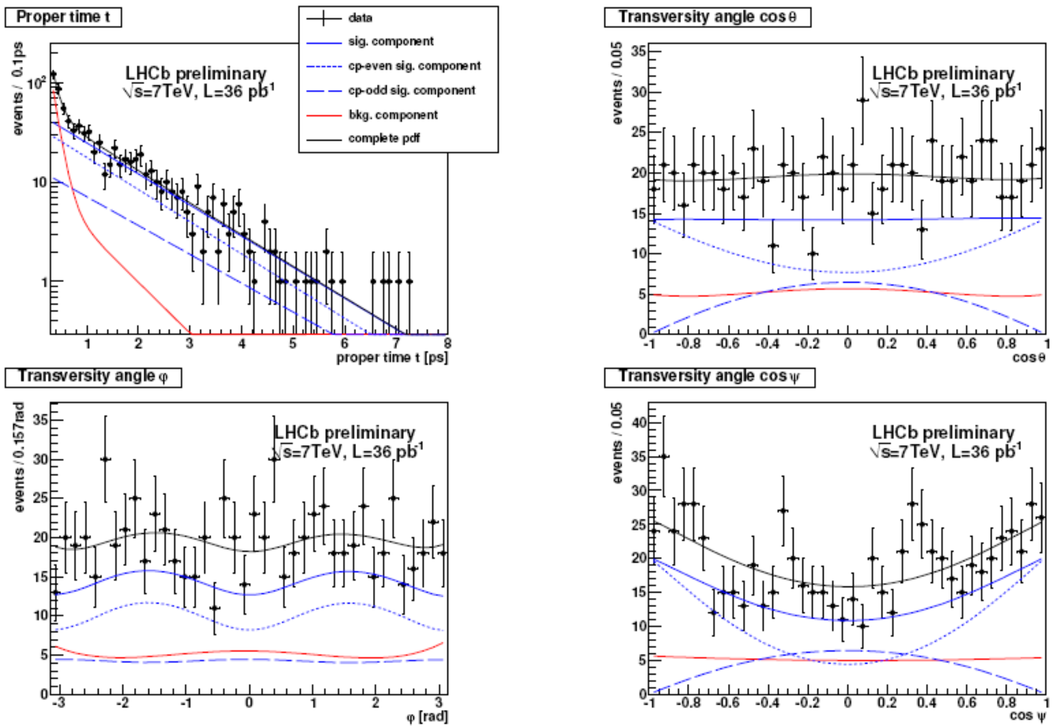


Untagged analysis of $B_s \rightarrow J/\psi\varphi$

(LHCb-CONF-2011-002)

Fix φ_s to zero, and fit

$$\frac{d^4\Gamma(B_s^0 \rightarrow J/\psi\phi)}{dt\, d\cos\theta\, d\phi\, d\cos\psi} = f(\phi_s, \Delta\Gamma_s, \Gamma_s, \Delta m_s, M_{B_s^0}, |A_\perp|, |A_\parallel|, \delta_\perp, \delta_\parallel)$$



LHCb preliminary (36 pb^{-1})

Γ_s	0.679 ± 0.036 ± 0.027
$\Delta\Gamma_s$	0.077 ± 0.119 ± 0.021
$\lvert A_0\rvert^2$	0.528 ± 0.040 ± 0.028
$\lvert A_\perp\rvert^2$	0.263 ± 0.056 ± 0.014
$\delta_\parallel$ (rad)	3.14 ± 0.52 ± 0.13

CDF note 10206 (5.2 fb^{-1})

Γ_s	0.653 ± 0.011 ± 0.005
$\Delta\Gamma_s$	0.075 ± 0.035 ± 0.010
$\lvert A_0\rvert^2$	0.524 ± 0.013 ± 0.015

(plus $|A_{||}|^2$ and $\delta_\perp$)

Flavour tagging (LHCb-CONF-2011-003)

- Initial flavour of B can be inferred from
  - Opposite Side: products of the other B meson
  - Same Side: fragmentation particles associated to signal B
- Optimized and calibrated using control channels

OS+SS-π	$\varepsilon_{\text{tag}}(\%)$	$\omega(\%)$	$\varepsilon_{\text{eff}}(\%)$
$B^0 \to D^{*-}\mu^+\nu_\mu$	28.9 ± 0.2	34.2 ± 0.8	2.87 ± 0.32
$B^+ \to J/\psi K^+$	23.0 ± 0.5	33.9 ± 1.1	2.38 ± 0.33
$B^0 \to J/\psi K^{*0}$	26.1 ± 0.9	33.6 ± 5.1	2.82 ± 0.87

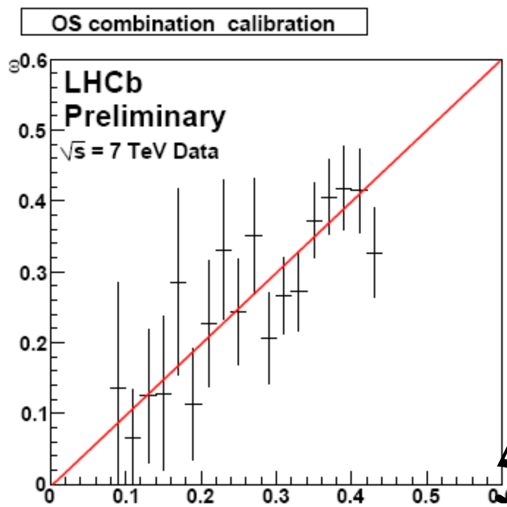
$\varepsilon_{\text{tag}} = \frac{R+W}{R+W+U}$ $\omega = \frac{W}{R+W}$ $\varepsilon_{\text{eff}} = \varepsilon_{\text{tag}} D^2 = \varepsilon_{\text{tag}}(1-2\omega)^2$

$B^+ \to J/\psi K^+$

Y: estimated per event mistag

X: calibrated mistag

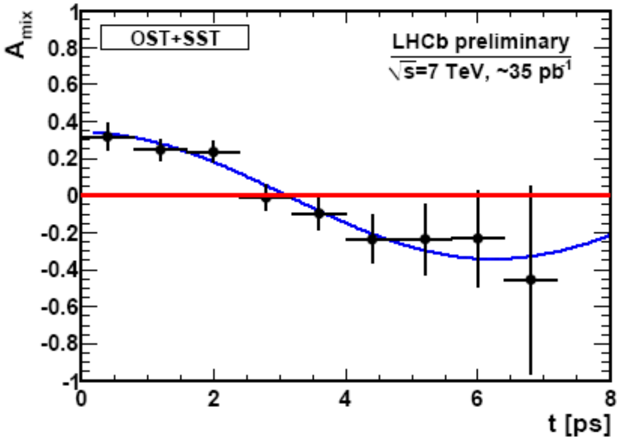
Fitted to a linear function



Δm_d and Δm_s

(LHCb-CONF-2011-010, LHCb-CONF-2011-005)

$B_d \rightarrow D^-(K^+\pi^-\pi^-)\pi^+$



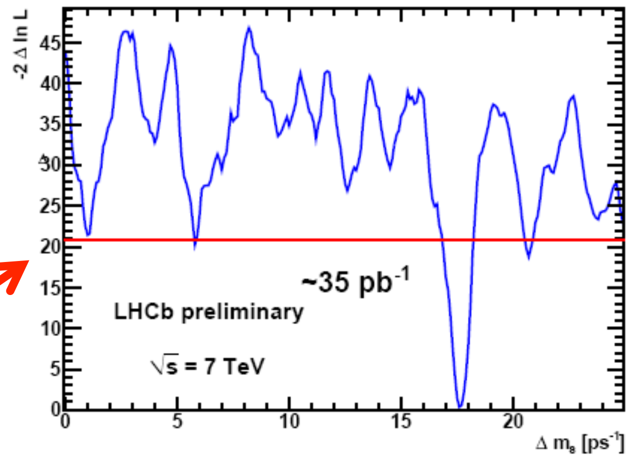
LHCb: Δm_d = 0.499 ± 0.032 ± 0.003 ps^{-1}
World average Δm_d = 0.507 ± 0.005 ps^{-1}

Only OST used, ε_{eff} =(3.5 ±2.1)%
Per event time resolution $<\sigma_t>$ ~ 40 fs

LHCb: Δm_s = 17.63 ± 0.11 ± 0.04 ps^{-1}
CDF: Δm_s = 17.77 ± 0.10 ± 0.07 ps^{-1}
(PRL 97, 242003)

Signal yields for Δm_s

LHCb (37 pb^{-1})		cf. CDF (1 fb^{-1})	
$B_s \rightarrow D_s(\phi\pi)\pi$	515 ± 25	$B_s \rightarrow D_s\pi$	4100
$B_s \rightarrow D_s(K^*K)\pi$	338 ± 27	$B_s \rightarrow D_s\pi$ partial	3100
$B_s \rightarrow D_s\pi$ non-reso	283 ± 27	$B_s \rightarrow D_s 3\pi$	1500
$B_s \rightarrow D_s 3\pi$	245 ± 46	semileptonic	61500



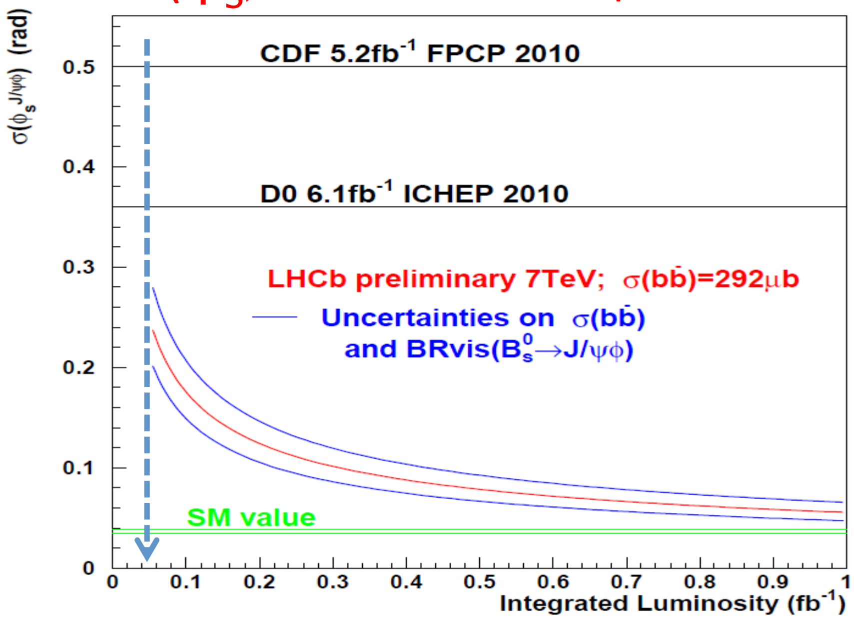
Redline: evaluated at infinite oscillation frequency

4.6σ significance

Tagged analysis of $B_s \to J/\psi\varphi$

- Analysis ongoing..
- Precision in φ_s using 36 pb^{-1} is expected to be comparable to the CDF precision →

$\sigma(\phi_S)$ vs L (2009 MC predictions)



	LHCb 36 pb^{-1}	CDF 5.2 fb^{-1}
$B_s^0 \to J/\psi\phi$	960	6500
Proper time resolution	50 fs	100 fs
OS tagging power	$2.5 \pm 0.8\%$	$1.2 \pm 0.2\%$
SS tagging power	work ongoing	$3.5 \pm 1.4\%$

LHCb has x30 more statistics with respect to CDF for same L
x2 proper time resolution
x2 OS tagging power

LHCb aims to make world's best measurement of φ_s with data from 2011 run

Where to look for NP signals @ LHCb?

The editor's choice

(Prospects for 2011)

- NP contributions in Rare decays:
  1) BR($B_{s,d} \rightarrow \mu\mu$), $D^0 \rightarrow \mu\mu$
  2) forward-backward asymmetry in $B_d \rightarrow K^*\mu\mu$
  3) non-SM photon polarization in exclusive $b \rightarrow s\gamma$ decays

-NP contributions in CP violating decays:

1) in box diagrams :
   - B_s mixing phase with $B_s \rightarrow J/\psi\varphi$ (and $B_s \rightarrow J/\psi\ f_0$)
   - CP phase in D mixing

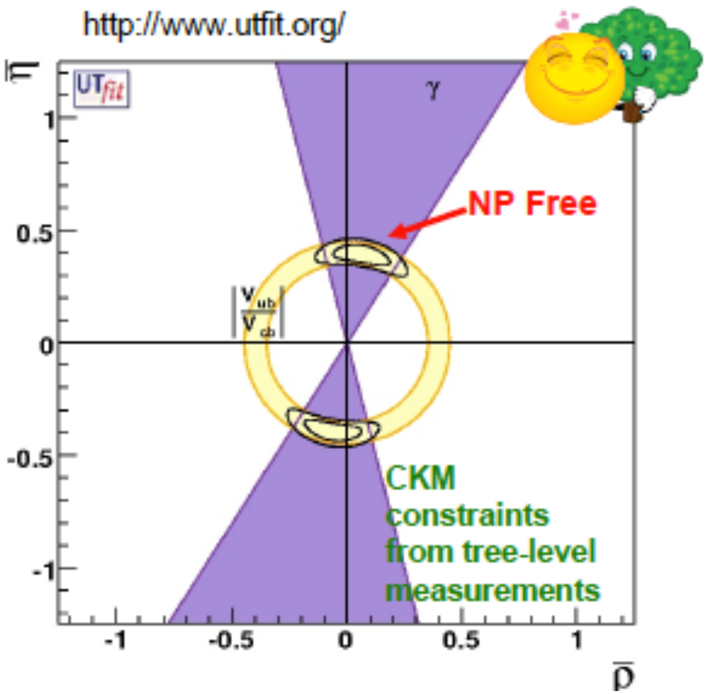
2) penguin diagrams:
   Compare two measurements of a given CP asymmetry, in processes with and without penguins
   $\rightarrow$any discrepancy is sign of New Physics

   - sin(2β) from $B^0 \rightarrow J/\psi K_S$ and sin(2β) from $B^0 \rightarrow \phi K_S$
   - **γ from $B_{(s)} \rightarrow D_{(s)}K$** and γ from $B^0 \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$
   - betas from $B_s \rightarrow J/\psi\varphi$ (f_0) and $B_s \rightarrow \varphi\varphi$

-LFV decays with muons in the final state: eg $\tau \rightarrow \mu\mu\mu$

Setting the CKM scale: γ from trees

Assume NP negligible in tree decays and fix Unitarity Triangle parameters from tree-level processes:



Tree decays w/o NP can determine: $|V_{ud}|$, $|V_{us}|$, $|V_{ub}|$, $|V_{cb}|$, and γ

γ [together with $|V_{ub}/V_{cb}|$] provides the SM signpost to be met by any NP model.

Present accuracy by direct measurement of γ from tree process B→D K is still poor:

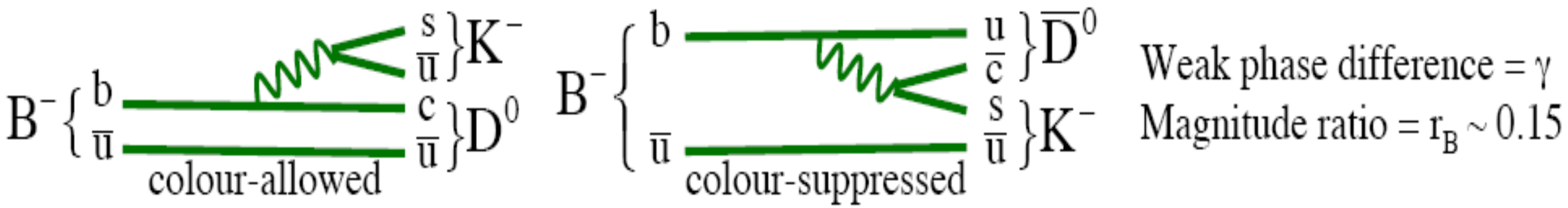
$\gamma\,(\mathrm{WA}) = (70\,^{+21}_{-25})°$

Current tension ($\sin(2\beta)$ & ε_k) calls for precise γ determination

→ Milestone of the LHCb program

Measuring γ @ LHCb

Milestone of the LHCb physics program is the measurement of 'B→ DK' direct asymmetries which are sensitives to the unitarity angle γ



Final state common to D^0 & D^0bar :
$K\pi$, KK, $\pi\pi$, $K\pi\pi\pi$, $K_S\pi\pi$, K_SKK…
allows for interference → γ

GLW : D^0 decays into CP eigenstates
ADS : D^0 decays to $K^-\pi^+$ (fav.) and $K^+\pi^-$(sup.)
GGSZ : $D^0 \rightarrow K_S\pi\pi$ (interference in Dalitz plot)

These decays are self-tagging:
→ no need to do a time-dependent analysis
→ only need the ratio of the different decay modes
Extract γ, r_B,δ_B simultaneously!

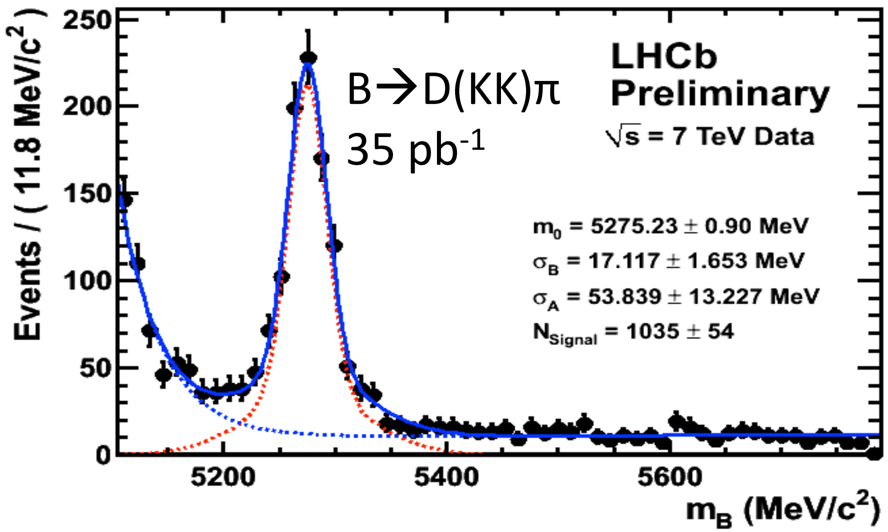
Crucial role of hadronic trigger and π/K separation in this analysis

Measuring γ @ LHCb

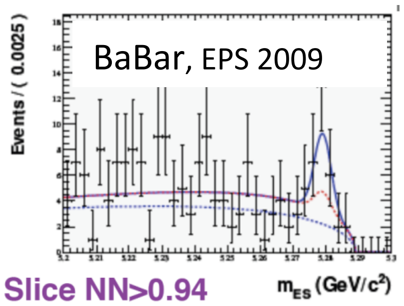
~ 1 fb^{-1} already offers possibilities to improve on knowledge from B factories

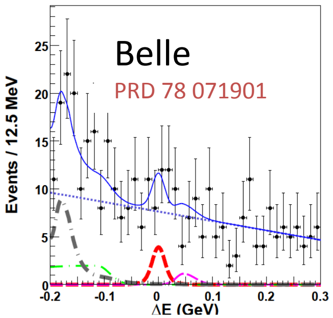
LHCb expected yields at 7 TeV, 1 fb^{-1}
Assuming r_B~0.1 (0.4) for $B^{\pm}$ (B^0)

Channel	Expected event yield
$B^- \to D(KK)K^-$	2000
$B^- \to D(\pi\pi)K^-$	750
$B^- \to D(K\pi)K^-$ favoured	20000
$B^- \to D(K\pi)K^-$ suppressed	400



eg. 'ADS' suppressed B→D(Kπ)K mode just beyond reach of B-factories → LHCb expects ~80 of these events with 200 pb^{-1}





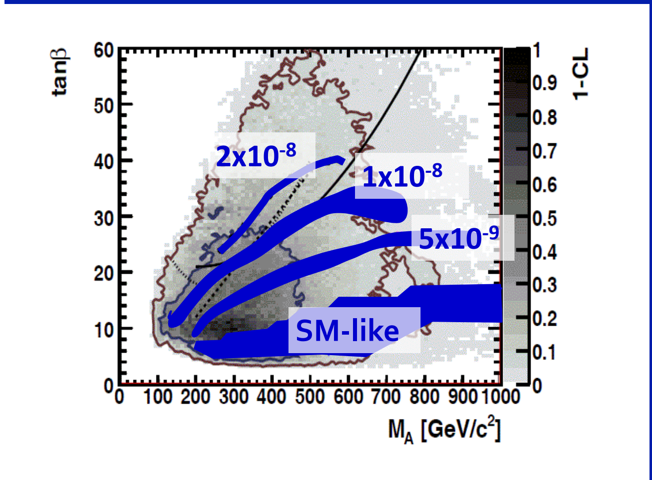
Combine all considered B→DK measurements and time dependent approaches from B_s system

$\sigma\gamma^{LHCb}$ ~ 10 ° with 1 fb^{-1} [end 2011]

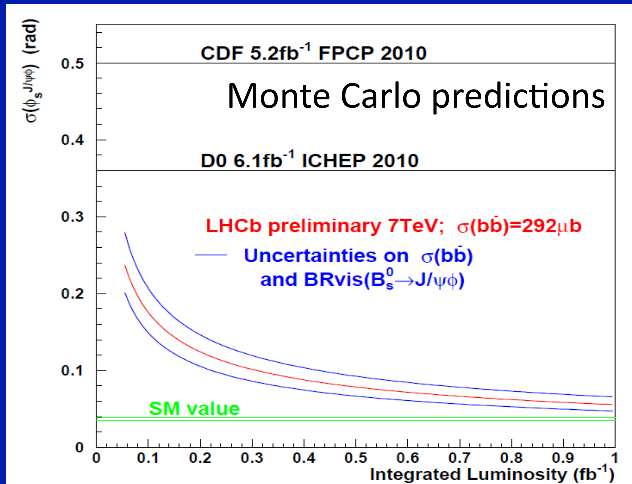
4. Prospects: LHCb with 1 fb^{-1}

(… sharpening the picture…).

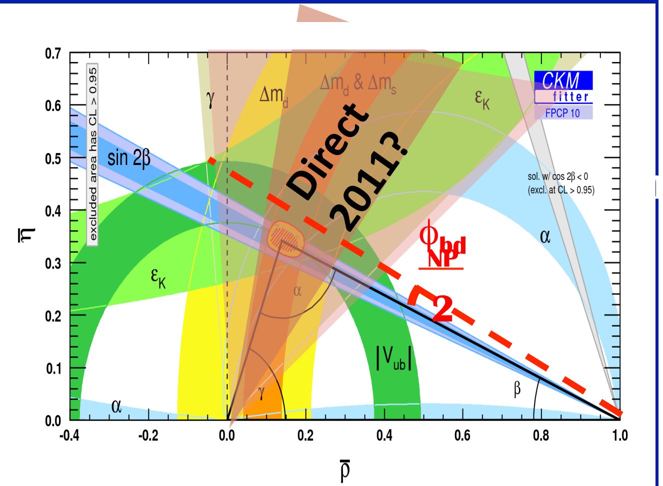
$B_s \to \mu\mu$



ϕ_s from $B_s \to J/\psi\phi$



γ from trees



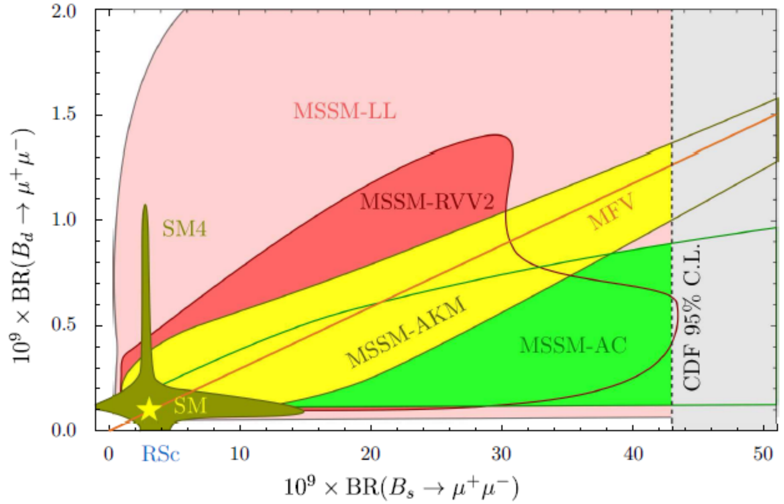
Impact on New Physics Models

LHCb will provide measurements essential to understand physics landscape that the coming decade will unveil. Lets consider two popular ideas.

Minimal Flavour Violation (MFV) hypothesis

All sources of flavour- and CP-violation in quarks will be same as SM. In this case searches for NP will be fruitless in CPV, but not in rare decays

e.g. In MFV BR($B_s \to \mu\mu$) *can* differ from SM but *not* BR($B_d \to \mu\mu$)/BR($B_s \to \mu\mu$)



SM with 4-families (SM4)

Add 2 new quarks (t', b') plus 5 new quark-mixing parameters

New CPV possibilities that could show up in D^0, B^0 and B_s system

Both proposals can be disproved / strongly constrained by LHCb in the coming years

Conclusions

•Flavour physics in the LHC era is an excellent window for new physics searches fully complementary to the direct searches approach.

•LHC and LHCb are performing amazingly well.
→ First results show the excellent quality of data collected so far.
-→ with only 37 pb^{-1} LHCb is already competitive in the $B_s \rightarrow \mu\mu$

•With the data collected in the 2011 run LHCb will have competitive results in the measurement of γ, $B_d \rightarrow K^*\mu\mu$ FB asymmetry CPV violating phase in B_s mixing, CPV in charm which will allow to clarify better the already observed anomalies in the Standard Model and possibly discover New Physics.

Thank you for your attention and… the best has still to come!

STOP

1.LHC: status of 2010-2011 run

2010:

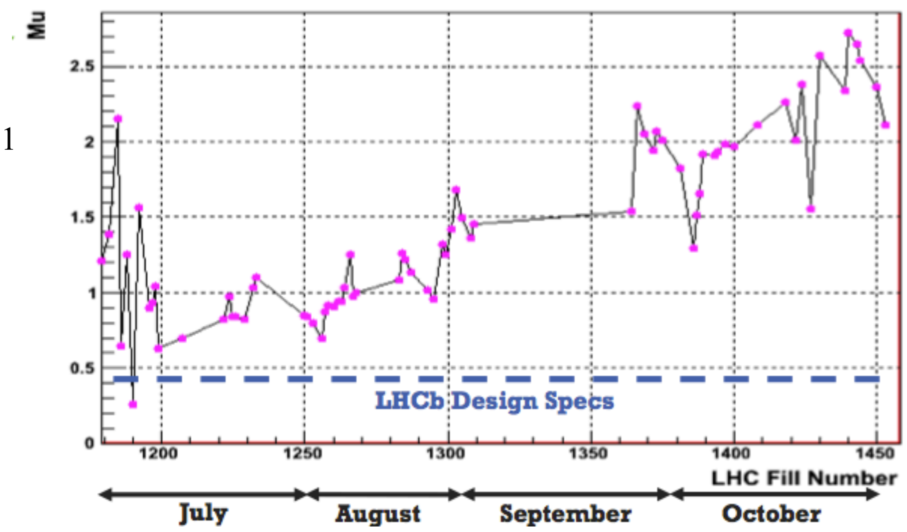
80% of L reached with 344 bunches

(2622 nominal) and $\beta^*\sim3.5$ m

($\beta^*\sim10$ m nominal) and $L_{peak}\sim1.6\ 10^{32}\ cm^{-2}\ s^{-1}$

→Number of visible pp interactions/crossing up to 2.7 (nominal=0.4).

Number of visible pp interactions per crossing in 2010



2011:

first stable beam last Sunday; reached $1.2\ 10^{30}\ cm^{-2}\ s^{-1}$ in ATLAS/CMS with 2 bunches per beam. $\beta^*\sim3$ m, $\mu=1.2$. After a short run at 1.38x 1.38 TeV the machine will go at 3.5x3.5 TeV and 75 ns scheme with $\beta^*=3$ m, $\varepsilon^*=2.5$ μm (possibly down to 1 μm), $Np\sim1.2\ 10^{11}$ /bunch, o(1000) bunches/beam

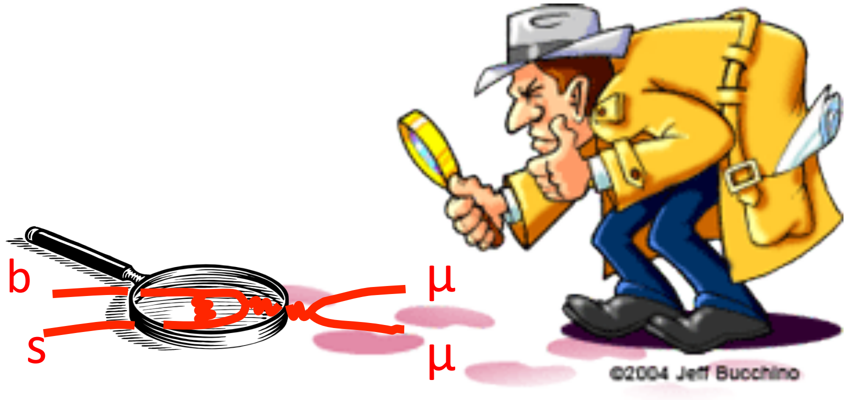
LHCb will not exceed $3\text{x}10^{32}\ cm^{-2}\ s^{-1}$ → luminosity leveling @ IP8.

2.Rare Decays @ LHC

Back to FCNC processes….

→In SM only allowed at loop level

→ powerful probe for possible NP.



The FCNC processes can be described by an effective Hamiltonian, in the form of an Operator Product Expansion:

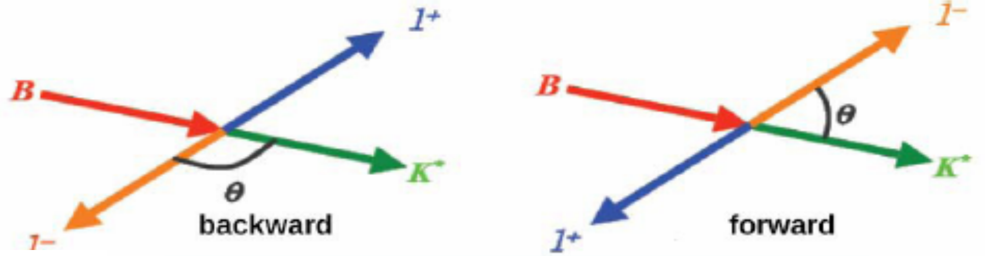
$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i [\underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C_i'(\mu) O_i'(\mu)}_{\text{right-handed part}}]$$

$i = 1,2$	Tree
$i = 3-6,8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9,10$	Electroweak penguin
$i = S$	Higgs (scalar) penguin
$i = P$	Pseudoscalar penguin

New physics modifies the Wilson coefficients affecting observable quantities as BRs [ex:B_s→μμ] (C_s, C_p), Angular distributions [B_d→K*μμ] (C_9,C_{10}, C_7) and Polarization [B_s→φγ] (C_7).

2.Intriguing hints from $B \to K^{(*)} l^+ l^-$

Forward backward asymmetry in $B^0 \to K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP



$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

$$A_{FB} = \int \frac{d^2 B(B \to K^* \mu^+ \mu^-)}{d\cos\theta} sgn(\cos\theta) \;\propto\; \mathrm{Re}\{C_{10}^*[q^2 C_9^{eff}(q^2) + r(q^2) C_7]\}$$

θ = angle between μ^+ & B in the dilepton rest frame

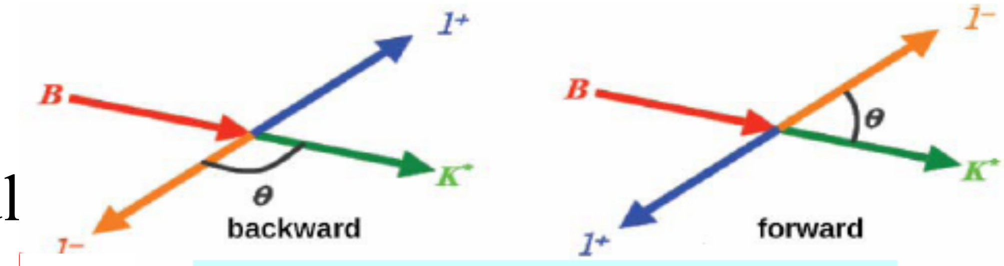
q^2 = dilepton invariant mass

- γ penguin [dipole] ⇔ $b \to s\gamma$ (C_7)
- γ peng. [vector] + (Z & box) (C_9)
- Z peng. + box [axial] (C_{10})

- Interference of axial & vector currents ➔ direct access to relative phases of the Wilson coefficients.
- Uncertainties of hadronic form factors under control in the low-q^2 region.

2.Intriguing hints from $B \rightarrow K^{(*)} l^+ l^-$

Forward backward asymmetry in $B^0 \rightarrow K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP



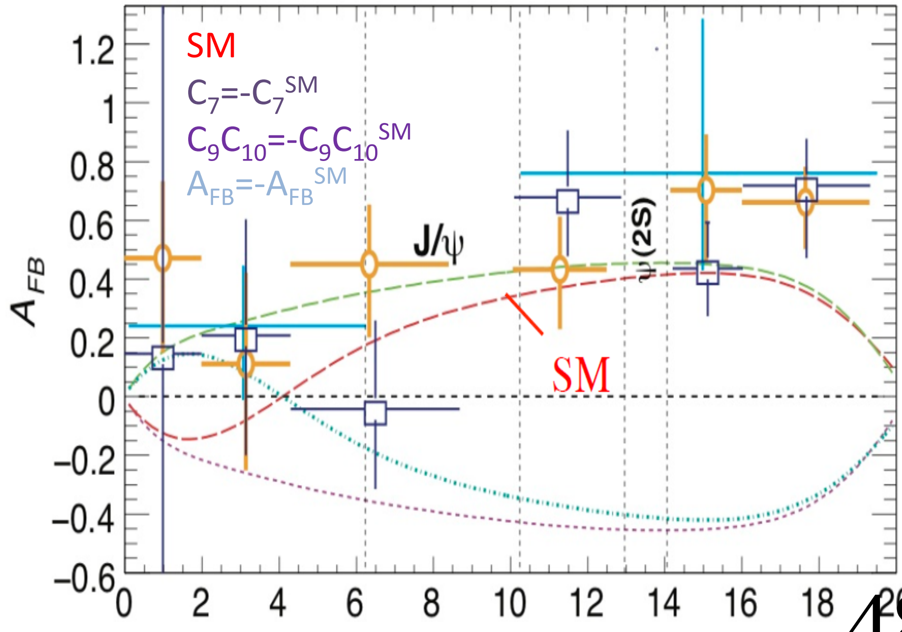
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

Early results are showing intriguing hints….

250 K* ll
[80% of data]

100 K* ll
[75% of data

100 K*ll
[$4.4\ fb^{-1}$]



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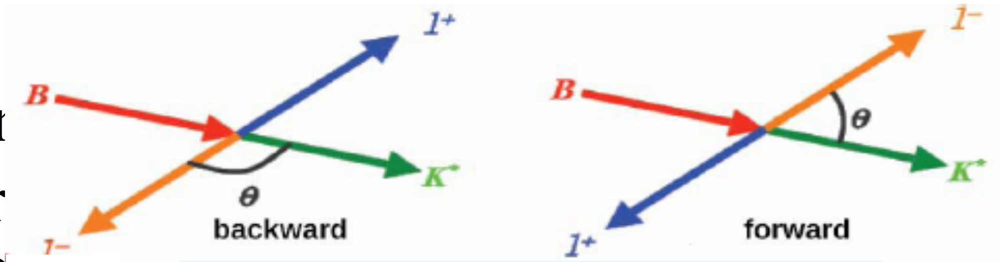


$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

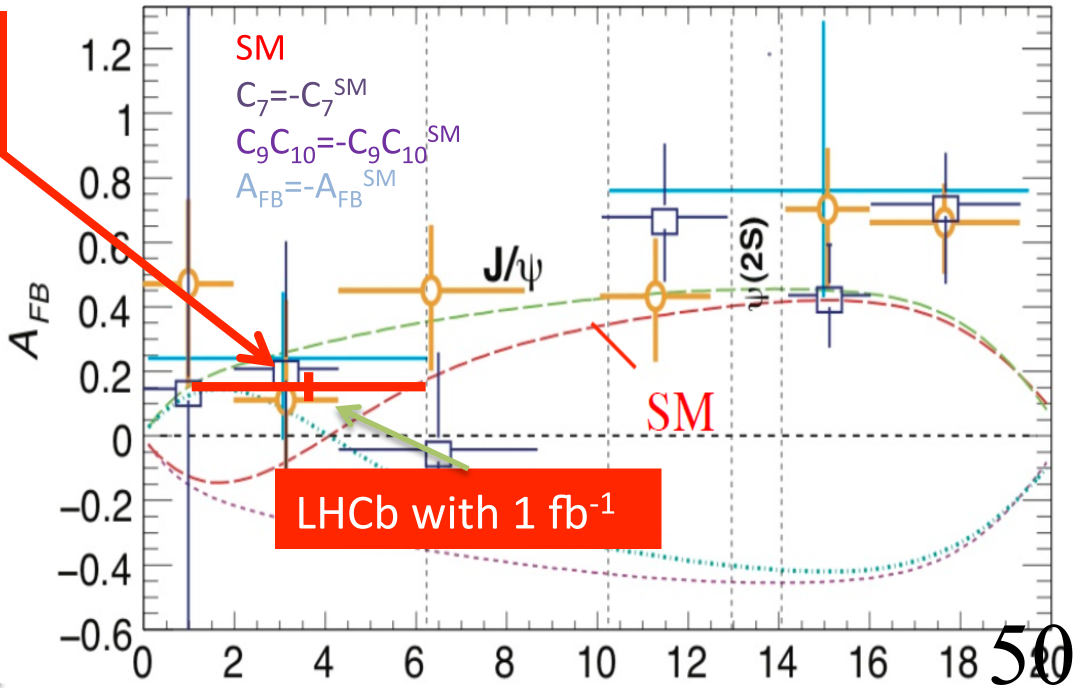
… and LHCb can help in understanding further the situation!

1400 K*ll [1 fb^{-1}]

250 K* ll [80% of data]

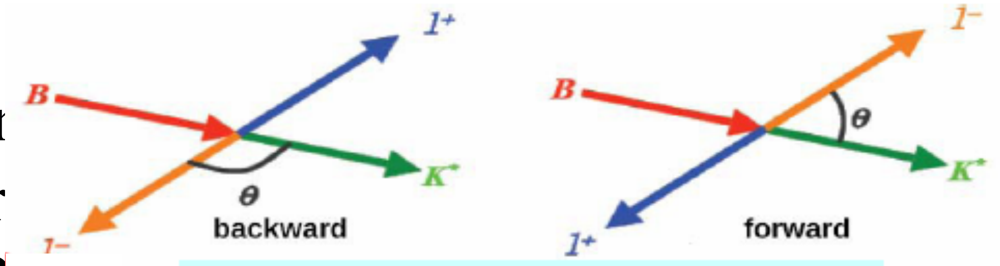
100 K* ll [75% of data

100 K*ll [4.4 fb^{-1}]



2.$B_d \to K^* \mu^+ \mu^-$ @ LHCb

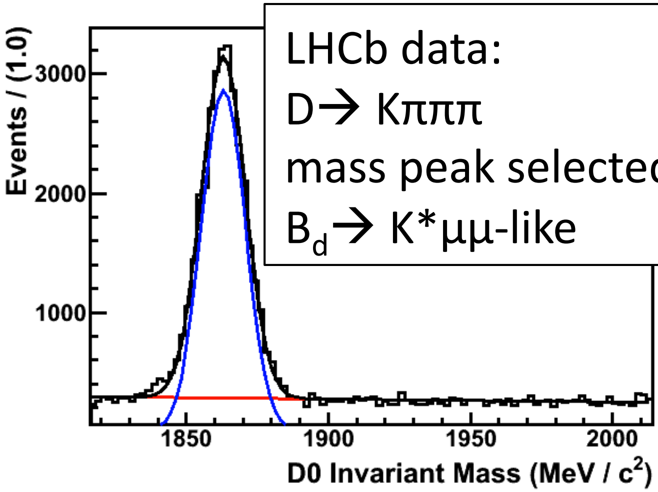
Forward backward asymmetry in $B^0 \to K^* l^+ l^-$ is a extremely powerful observable for testing SM vs NP



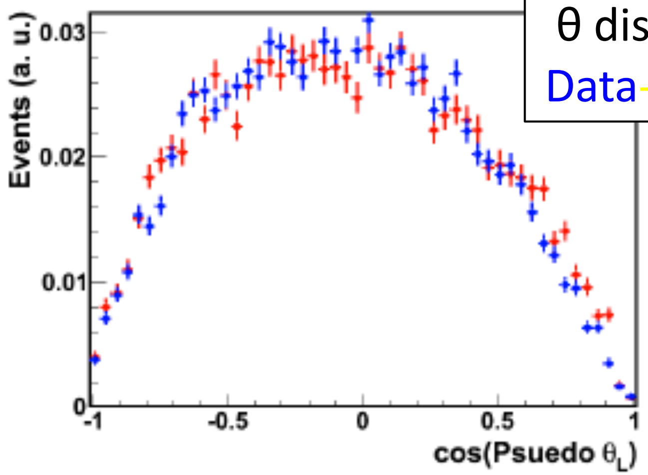
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

Main experimental problem: control of acceptance biases introduced by detector acceptance, trigger and selection:

→ use topologically similar and abundant control channels as $D \to K\pi\pi\pi$:



LHCb data:
$D \to K\pi\pi\pi$
mass peak selected
$B_d \to K^*\mu\mu$-like



θ distribution:
Data-MC comparison

Good agreement data and Monte Carlo:
→ The angular biases predicted from MC are reliable

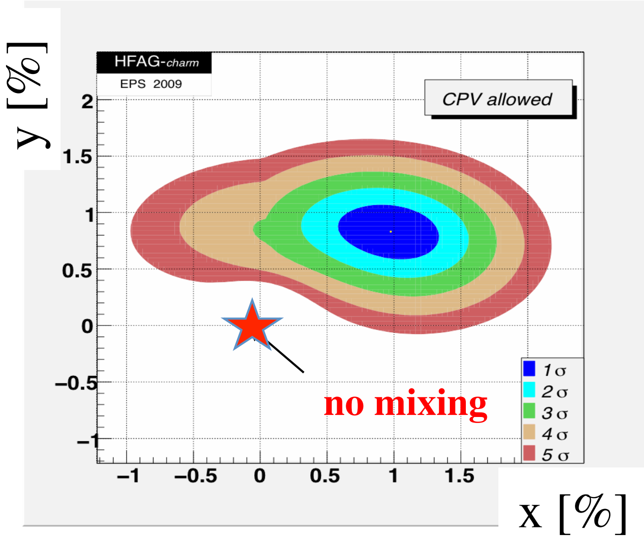
3.Prospects in the Charm sector

Charm physics has been for many years shadowed by the successes of K decays and B decays, due to the fact that:

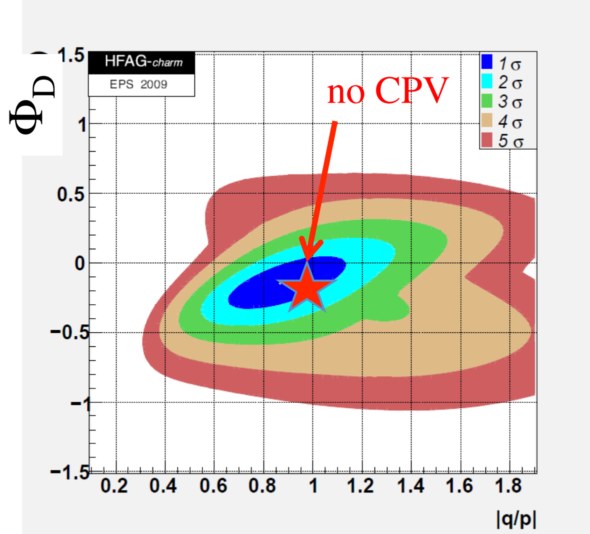
- the GIM mechanism is very effective in suppressing the FCNC transitions;
- long distance contributions prevent the evaluation of the ΔM_D;
- insensitivity to top physics in the loops.

However, large $D^0 - D^0$ mixing discovered in 2007 and good prospects for the study of CP violation in charm gave new impetus to this field.

"No-mixing" excluded at 10.2 σ:



All measurements consistent with no CPV:



Present constraints on CPV weak because CPV ~ $x_D \sin(2\varphi_D)$ and x_D~1%
→required sub-0.1% precision for CPV sensitivity!

3.Open Charm cross section at the LHC

Statistics at the LHC is not a problem….

Putting together:

$D^0 \rightarrow K\,\pi$,

$D^+ \rightarrow K\,\pi\pi$

$D^* \rightarrow D^0(K\,\pi)\,\pi$

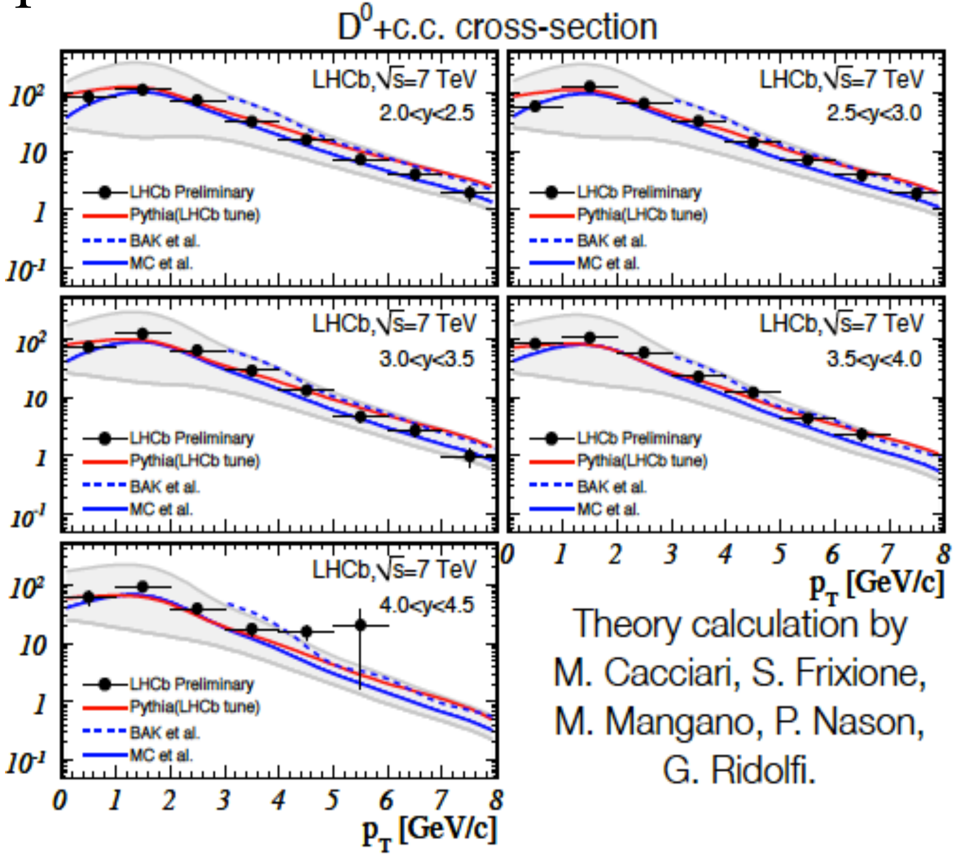
$D^+ \rightarrow \phi\,\pi$

and extrapolating to 4π

we get:

$\sigma(pp \rightarrow cc) = (6.10 \pm 0.93)$ mb

x 20 $\sigma(pp \rightarrow bb)$!



$$\sigma(c\bar{c}, D^0) = 1280 \pm 36 \pm 151 \pm 150\,\mu\text{b} = 1280 \pm 216\,\mu\text{b}$$

3.Charm mixing studies at LHCb

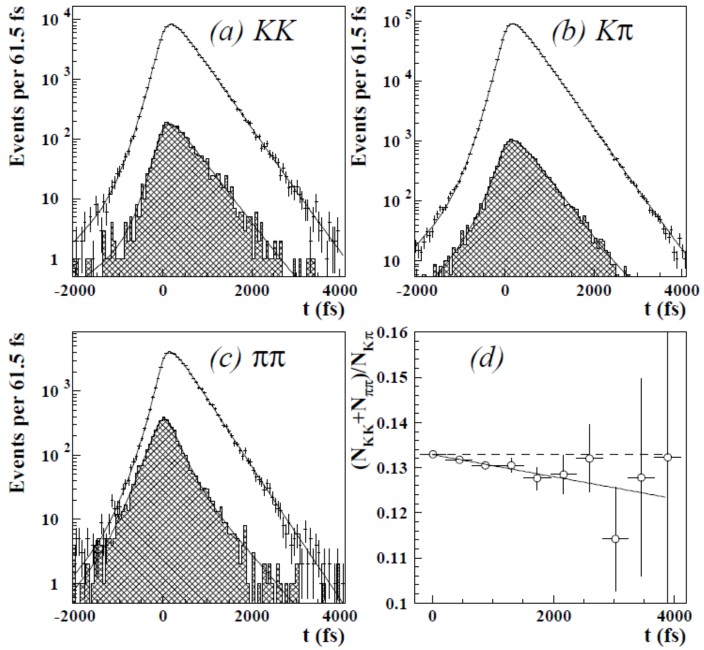
Example mixing analysis is measurement of "y_{CP}", which is D^0 width splitting parameter modified by CP-violating effects. Comparison to pure "y" measurements probes for CP-violation, as does measurement of pure CP-violating observable A_Γ

y_{CP}: compare lifetime of $D^0 \to$ CP-eigenstate, eg. KK or ππ, to $D^0 \to$ non-eigenstate eg. Kπ [untagged samples]

$$\boxed{y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1}$$

A_Γ: compare D^0 and $\overline{D}^0 \to KK$ lifetimes [tagged samples]

$$\boxed{A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}}$$

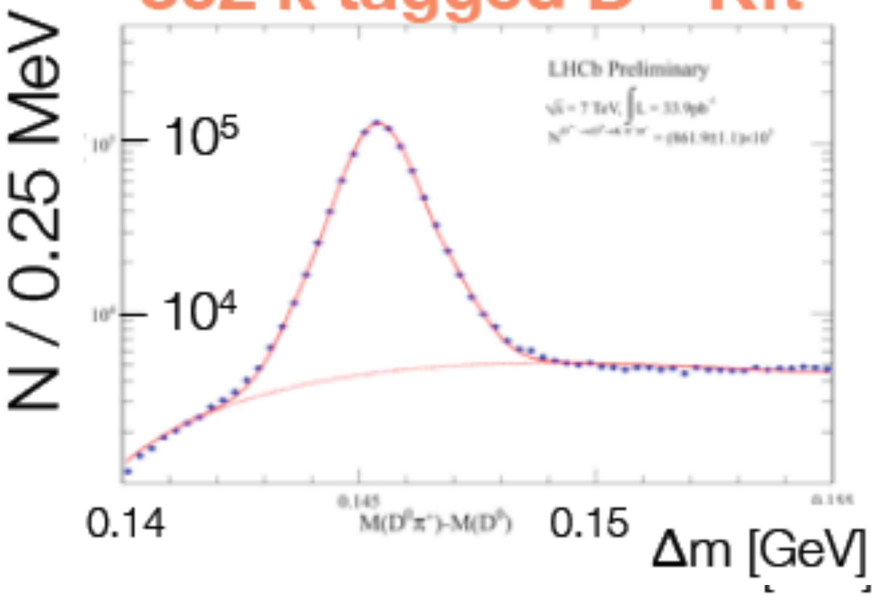


Belle, PRL 98 (2007) 211803

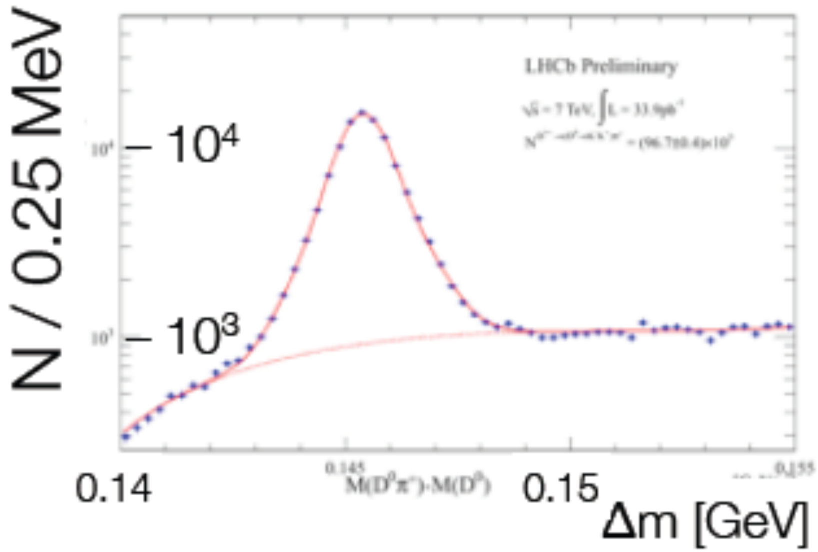
y_{CP}: current world best by Babar (2.6 M Kπ and 260k KK in 0.38/ab
→Statistical precision 0.22% (PRD80:071103 (2009))
A_Γ: current world best from Babar+Belle (180k tagged KK)
--> Statistical precision 0.25%

3.Charm mixing studies at LHCb

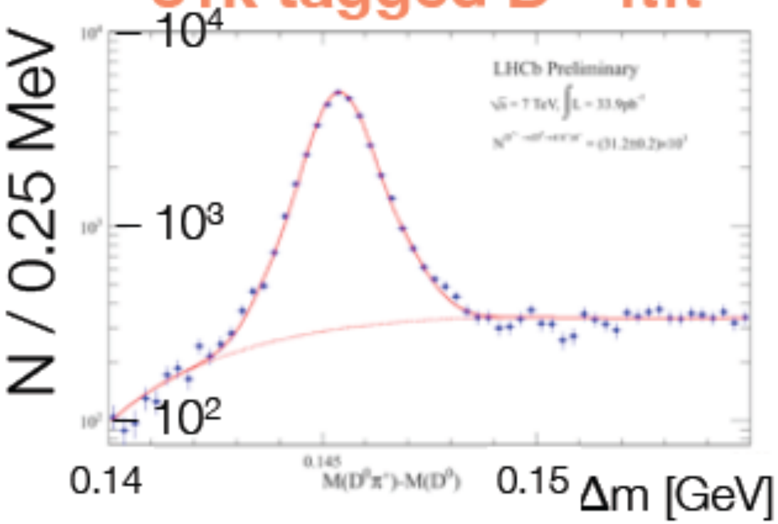
862 k tagged D→Kπ



97 k tagged D→KK



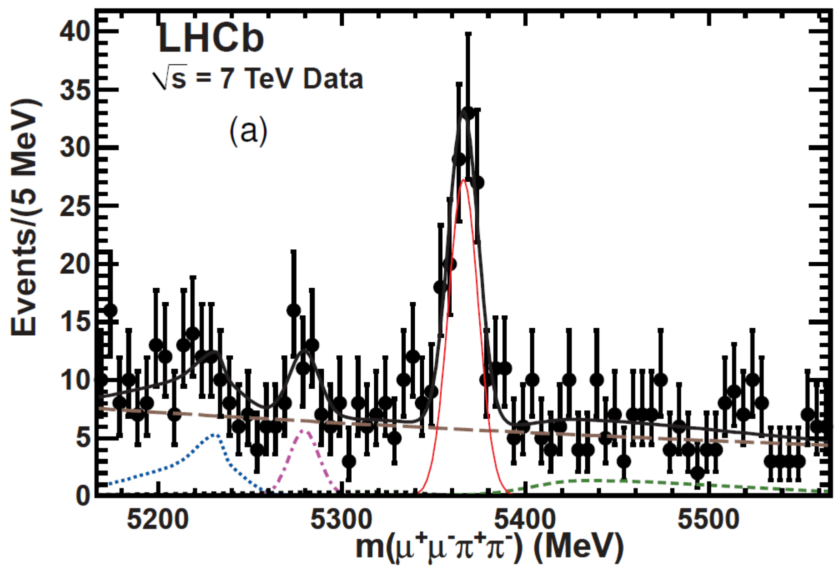
31k tagged D→ππ

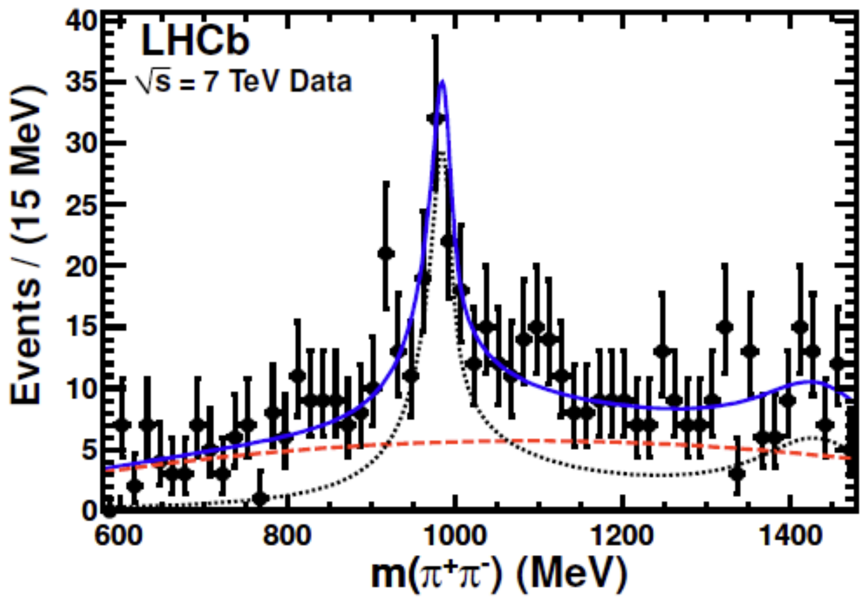


Enough events for competitive y_{CP}, A_Γ measurements in 2010 data - 2011 data will increase this again by more than an order of magnitude

4. First observation of $B_s \to J/\psi f_0$

LHCb, arXiv:1102.0206[hep-ex]





LHCb

$$R_{f_0/\phi} \equiv \frac{\Gamma\left(B_s^0 \to J/\psi f_0, f_0 \to \pi^+\pi^-\right)}{\Gamma\left(B_s^0 \to J/\psi\phi, \phi \to K^+K^-\right)} = 0.252^{+0.046+0.2027}_{-0.032-0.003}$$

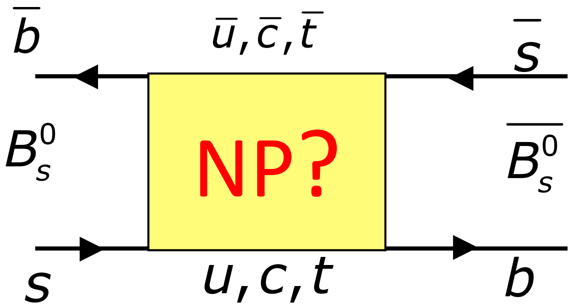
Prediction:

(S. Stone and L. Zhang, PRD 79, 074024)

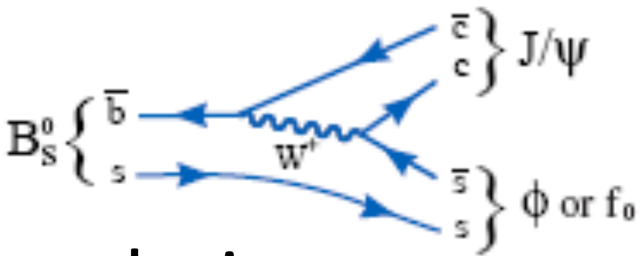
$$R_{f_0/\phi} \equiv \frac{\Gamma\left(B_s^0 \to J/\psi f_0, f_0 \to \pi^+\pi^-\right)}{\Gamma\left(B_s^0 \to J/\psi\phi, \phi \to K^+K^-\right)} \approx 0.2$$

4. Implication

- Sensitive probe of NP in B_s mixing just as $B_s \rightarrow J/\psi\phi$



Decay: dominated by SM tree



- CP odd, no need for angular analysis to disentangle CP eigenstates
- Good precision to complement $B_s \rightarrow J/\psi\phi$
- Can use $f_0 \rightarrow KK$ to resolve sign ambiguity in ϕ_s

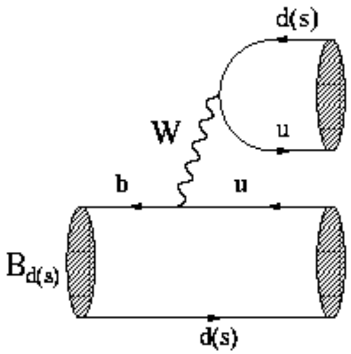
(JHEP 0909:074, 2009, Y. Xie *et al.*)

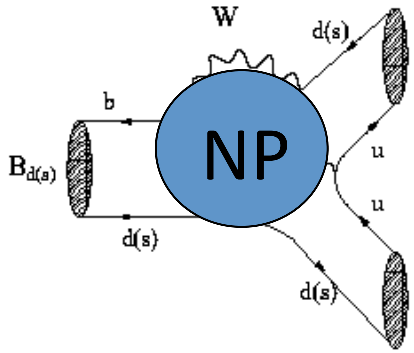
Search for NP in penguin diagrams

- ❑Direct CP violation in $B \longrightarrow K\pi$
- ❑First observation of $B_s \longrightarrow K^{*0}\overline{K^{*0}}$

$B \to hh$

- Sensitive probe of NP in penguin diagrams



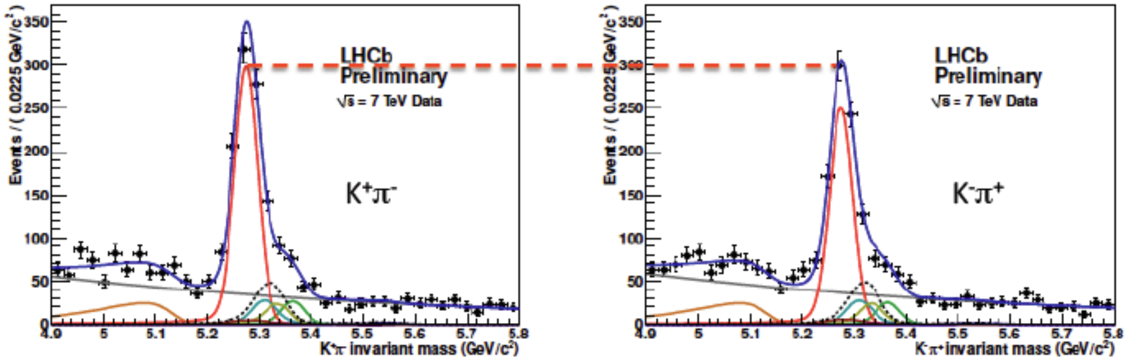


- Observables
  - Time-dependent CP asymmetries in $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^+$
  - Direct CP asymmetries

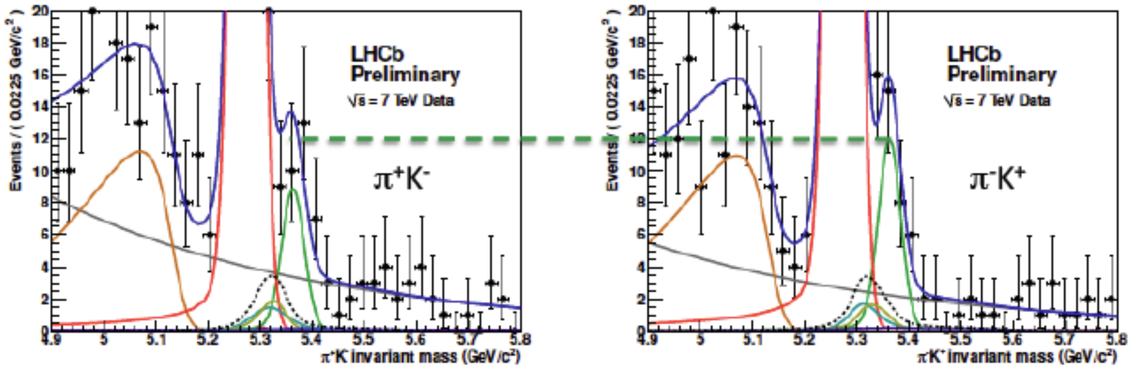
$$A_{CP} = (N_{\bar{B}\to\bar{f}} - N_{B\to f})/(N_{\bar{B}\to\bar{f}} + N_{B\to f})$$

Direct CP violation in $B_{d/s} \rightarrow K\pi$

Raw CP asymmetry in $B^0 \rightarrow K\pi$ decays: -0.086 ± 0.033



Raw CP asymmetry in $B_s \rightarrow \pi K$ decays: 0.15 ± 0.19



$$A_{CP}\left(B^0 \rightarrow K^+\pi^-\right) = -0.074 \pm 0.033 \pm 0.008$$

$$A_{CP}\left(B_s^0 \rightarrow \pi^+K^-\right) = 0.15 \pm 0.19 \pm 0.02$$

Data-driven correction:

$$A_{CP} = A_{CP}^{RAW} - A_D(K\pi) - \kappa A_P$$

detector asymmetry

A_d = -0.004±0.004

production asymmetry

A_p= -0.025±0.014±0.010

Oscillation factors *k*

Channel	κ
$B^0 \rightarrow K^+\pi^-$	0.33
$B_s^0 \rightarrow \pi^+K^-$	0.015

HFAG

$$A_{CP}\left(B^0 \rightarrow K^+\pi^-\right) = -0.098^{0.012}_{-0.011}$$

$$A_{CP}\left(B_s^0 \rightarrow \pi^+K^-\right) = 0.39 \pm 0.17$$

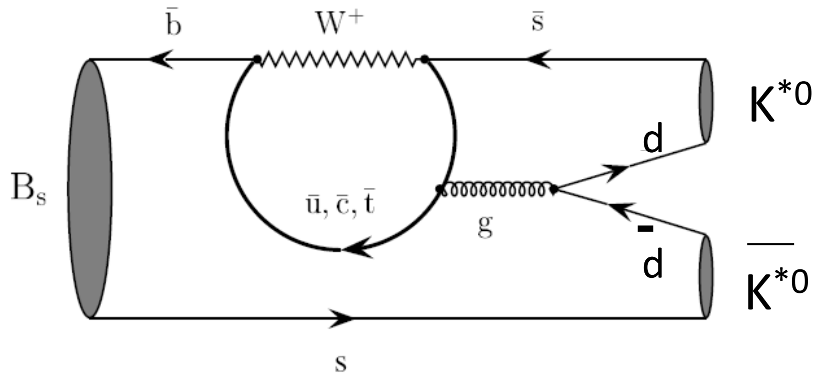
Physics in $B_s \rightarrow K^{*0}\overline{K}^{*0}$

b→s penguin process

SM decay amplitude

$$A(B_s \to K^{*0}\bar{K}^{*0}) = -V_{tb}^* V_{ts}\, P_s - V_{ub}^* V_{us}\, P_s^{\rm GIM}$$

dominated by top loop P_s



Null test of SM

$\Phi_M - 2\Phi_D = 0$ ⇒ mixing-induced asymmetry
direct CP asymmetry

$$S(B_s \to K^{*0}\overline{K}^{*0}) = 0$$
$$C(B_s \to K^{*0}\overline{K}^{*0}) = 0$$

CKM suppressed up and charm loops P_s^{GIM}
controlled using d↔s channel $B_d \rightarrow K^{*0}\overline{K}^{*0}$
(M. Ciuchini, M. Pierini, L. Silvestrini, PRL 100, 031802)

Sensitive to NP that affects weak phases of box and penguin diagrams differently

Ratio of fragmentation fractions

We use f_d/f_s=3.71±0.47, a recent combinaton of LEP+Tevatron data by HFAG, with 13% uncertainty, dominated by LEP measurements

B species	Z^0 fractions [%]	Tevatron fractions [%]
$B^\pm$	40.4±1.2	33.3 ± 3.0
B^0	40.4±1.2	33.3 ± 3.0
B_s	10.9±1.2	12.1 ± 1.5
Λ_b	8.3±2.0	21.4 ± 6.8

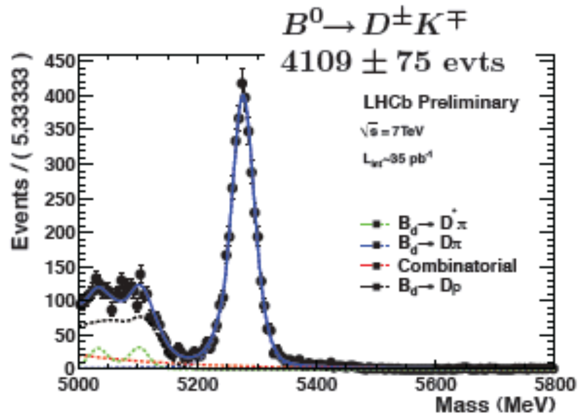
HFAG: http://www.slac.stanford.edu/xorg/hfag/osc/end_2009/#FRAC
Tevatron results from PLB, 667,1 (2008)

LHCb is measuring them using semileptonic decays and hadronic $B_{(s)}\to Dh$ decays *(method described in Phys.Rev.D83, 014017 (2011)*

Ratio of fragmentation fractions

$$BR = BR_{cal} \cdot \frac{f_{cal}}{f_{B_s}} \cdot \frac{\varepsilon_{cal}^{Rec} \cdot \varepsilon_{cal}^{Sel} \cdot \varepsilon_{cal}^{Trig}}{\varepsilon_{Bs}^{Rec} \cdot \varepsilon_{Bs}^{Sel} \cdot \varepsilon_{Bs}^{Trig}} \cdot \frac{N_{B\to\mu\mu}}{N_{cal}} = \alpha \cdot N_{B\to\mu\mu}$$

Currently use HFAG average of LEP/Tevatron value: **fd/fs=3.71±0.47**



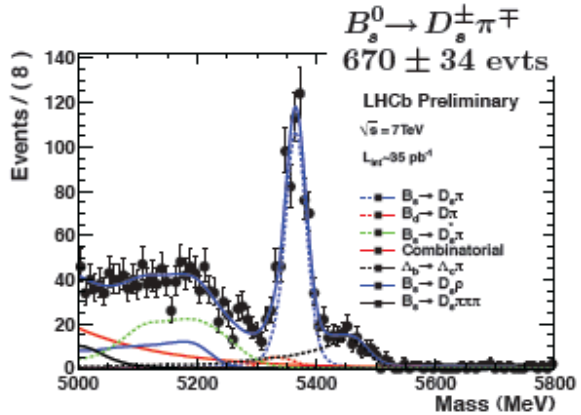
LHCb already provides (preliminary) results

- Measure fd/fs in the relative yields of $B^0 \to D^\pm K^\pm$ or $B^0 \to D^\pm \pi^\pm$ to $B_S \to D_S \pi^\pm$

  NEW: with 35pb^{-1} LHCb measures

  $$\boxed{\frac{f_{B_d^0}}{f_{B_s}} = 4.02 \pm 0.52}$$ (using $B^0 \to D^\pm \pi^\pm$)

  Fleischer et al, Phys.Rev.D83,014017 (2011)
  LHCb-CONF-2011-013



- Also preliminary result from semileptonics:

  $$\frac{f_{B_d^0}}{f_{B_s}} = 3.84 \pm 0.34$$ preliminary

Statistical Method

We have si, bi, di=Nobs:

$$X_i = \frac{Poisson(d_i, < d_i >= s_i + b_i)}{Poisson(d_i, < d_i >= b_i)}$$

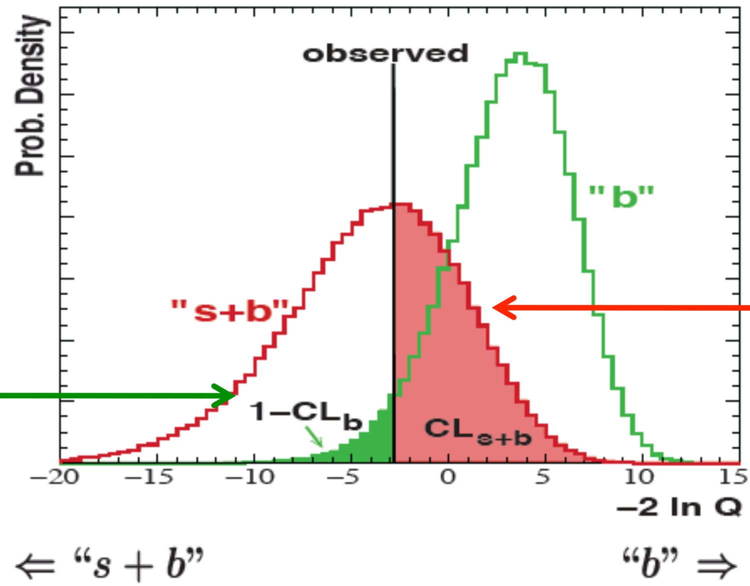
$$X = \prod_i^N X_i$$

$$\boxed{CL_{s+b} = P_{s+b}(X \leq X^{OBSERVED})}$$

$$\boxed{CL_b = P_b(X \leq X^{OBSERVED})}$$

CL= CL(s+b)/CLb

1-CL_b measures the Incompatibility with the background only hypothesis

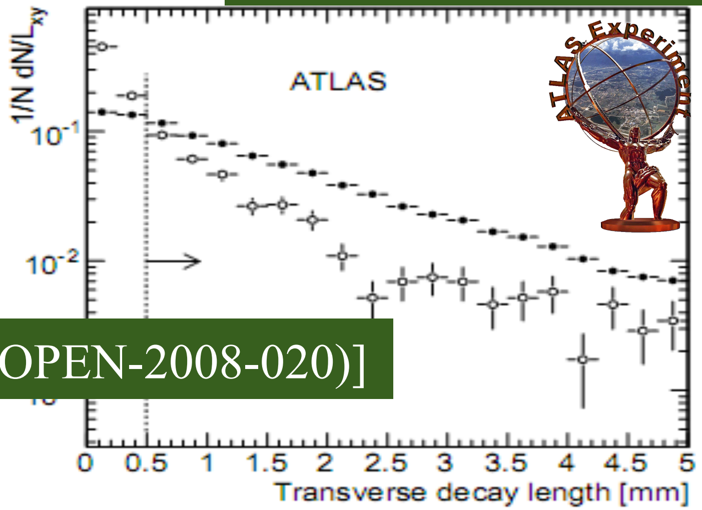


CL_{s+b} measures the Incompatibility with S+B hypothesis

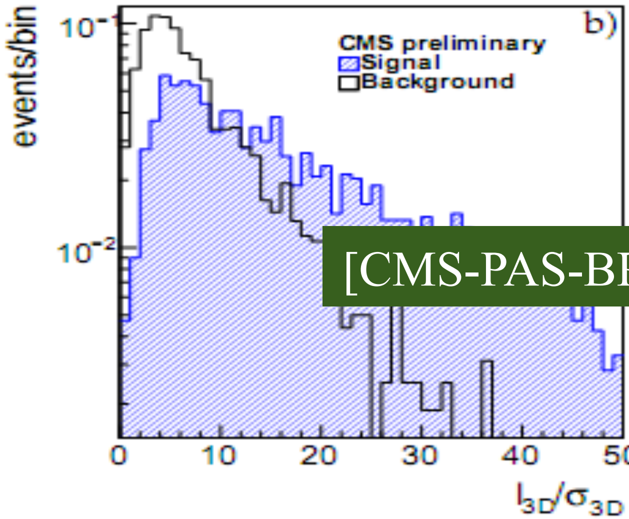
$B_s \rightarrow \mu\mu$ @ ATLAS/CMS

Cut based analysis: separate signal from background by using high discriminant variables such as pointing , isolation and secondary vertex displacement:

Eg: Distance of flight and distance of flight significance:



[CERN-OPEN-2008-020)]



[CMS-PAS-BPH-07-001 (2009)]

Experiment	N sig	N bkg	90% CL limit in absence of signal
ATLAS (10 fb^{-1}) $\sigma(bb)$=500 ub	5.6 events	14^{+13}_{-10} events (only $bb\rightarrow\mu\mu$)	-------
CMS (1 fb^{-1}) $\sigma(bb)$=500 ub	2.36 events	6.53 events (2.5 $bb\rightarrow\mu\mu$)	$< 1.6 \times 10^{-8}$

D. Karlen, Comp. Phys.12 (1998) 380

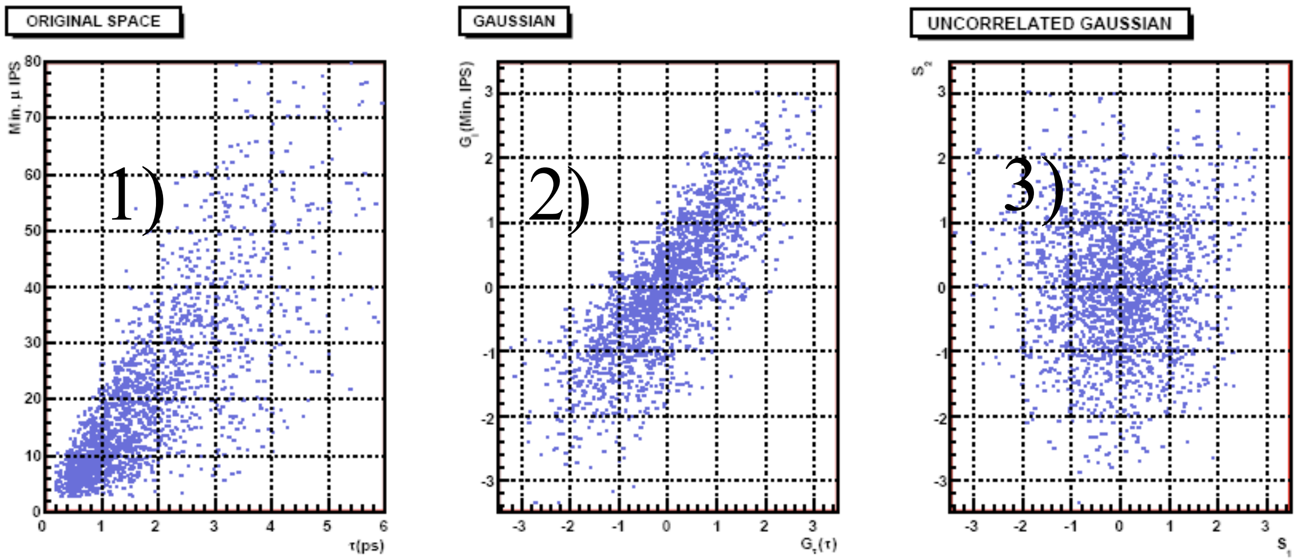
Geometrical Likelihood

- How the decorrelation is done:

1). Input variables → 2) Gaussian variables

→ In this space the correlations are more linear: easier to decorrelate

3) Decorrelation is applied and the variables are re-gaussianized



Gaussian and independent variables:
→ Build $\chi 2$

→Tranformation under signal hypothesis: χ^2_S

→Transformation under background hypothesis: χ^2_B

Discriminating variable: GL = $\chi^2_S - \chi^2_B$ → kept flat for signal

Trigger configurations

Data samples grouped in 5 trigger categories:

- Muon lines stable for 90% of the data set
- Hadron lines: 80% of L taken with L0(h) ET>3.6 and SPD<450 /900

→ important for calibration/normalization channels

L0:

TCK category	$L0-\mu$ p_T (GeV/c) / nSPD	$L0-di\mu$ p_{T1} (GeV/c) / p_{T2} (GeV/c) / nSPD	$L0-hadron$ p_T (GeV/c) / nSPD	integrated luminosity
1a	1.0/ -	1.0 / 0.4 / -	2.26 / -	2.2 pb^{-1}
1b	1.0 / 600	1.0 / 0.4 / 600	2.26 / 600	1 pb^{-1}
2	1.4 / 900	0.56 / 0.48 / 900	2.6 / 900	2.3 pb^{-1}
3a	1.4 / 900	0.56 / 0.48 / 900	3.6 / 900	17.3 pb^{-1}
3b	1.4 / 900	0.56 / 0.48 / 900	3.6 / 450	11.9 pb^{-1}

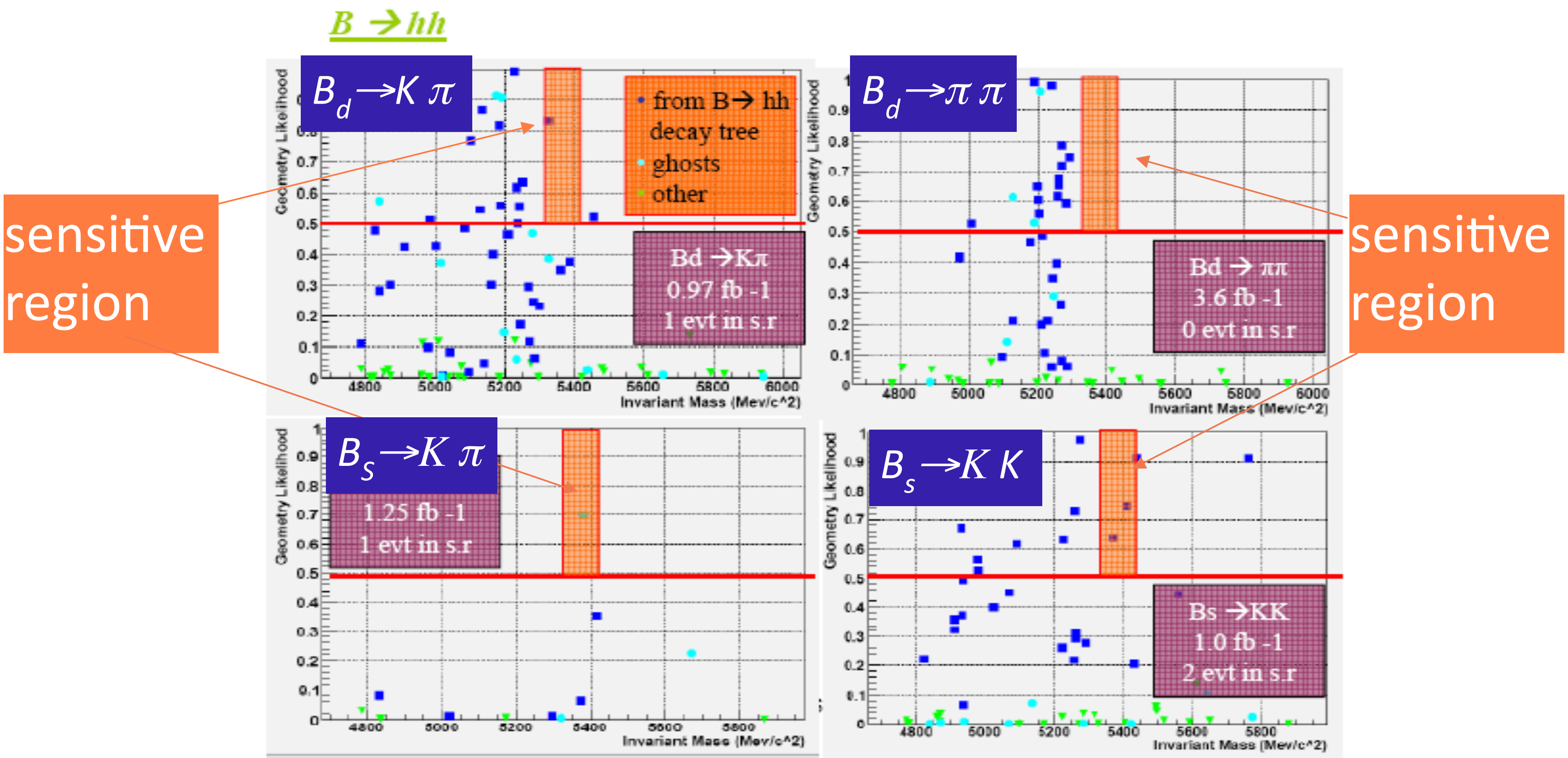
HLT1:

TCK category	Hlt1SingleMuonNoIP p_T (GeV/c) / prescale	Hlt1TrackMuon p_T/ IP (mm)/ IPS	Hlt1TrackAllL0 p_T (GeV/c) / IP/ IPS
1a	1.35 / 1	-	-
1b	1.35 / 1	-	-
2	1.8 / 1	800 / 0.11 / 5	1450 / 0.11 / $\sqrt{50}$
3a	1.8 / 0.2–1	800 / 0.11 / 5	1850 / 0.11 / $\sqrt{50}$
3b	1.8 / 0.2–1	800 / 0.11 / 5	1850 / 0.11 / $\sqrt{50}$

HLT2:

Background from B→hh modes

B→ hh background in the Geometry Likelihood vs M(μμ) plane

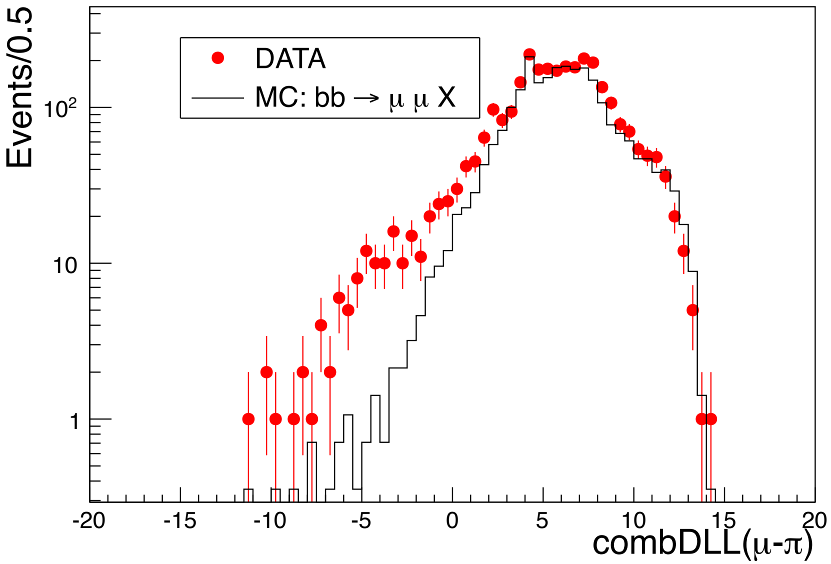


B→ hh background in the sensitive region is completely negligible with respect the bb→μμ component

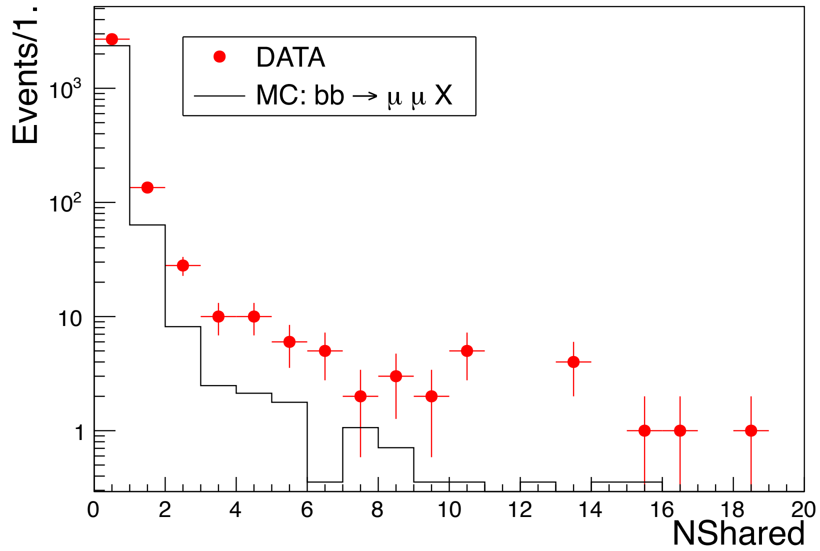
Background composition

- The background after the selection is dominated by real muons (mostly bb→μμX component):

MuonID Likelihood



Number of Muon Hits shared between tracks



Exact knowledge of the background level in MC is not required as the background in the signal region is anyhow extracted from sidebands of the mass distribution in data

Summary of parameters entering in the limit computation

Signal parameters

Normalizations	
f_d/f_s	3.71±0.47
$\alpha_{B_s^0\to\mu^+\mu^-}$	$(8.6 \pm 1.1) \times 10^{-8}$
$\alpha_{B^0\to\mu^+\mu^-}$	$(2.24 \pm 0.16) \times 10^{-9}$
Signal GL$_{\mathrm{KS}}$ *p.d.f.*	
$N^{TIS}_{B^0_{(s)}\to h^+h^-}$ (total)	611 ± 76
$N^{TIS}_{B^0_{(s)}\to h^+h^-}$, GL bin 2	228 ± 86
$N^{TIS}_{B^0_{(s)}\to h^+h^-}$, GL bin 3	168 ± 38
$N^{TIS}_{B^0_{(s)}\to h^+h^-}$, GL bin 4	215 ± 23
Signal Mass *p.d.f.*	
Mean value for B^0	5275.01 ± 0.87 MeV/c^2
Mean value for B_s^0	5363.1 ± 1.5 MeV/c^2
Mass resolution	26.71 ± 0.95 MeV/c^2
Crystal Ball transition point	$\alpha = 2.11 \pm 0.05$

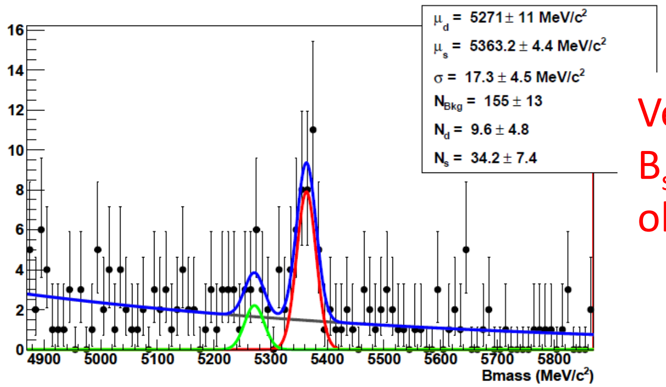
Background parameters

Background GL$_{\mathrm{KS}}$ *p.d.f.* for $B_s^0 \to \mu^+\mu^-$	
N^{bkg}, GL$_{\mathrm{KS}}$ bin 1	329.1±6.4
N^{bkg}, GL$_{\mathrm{KS}}$ bin 2	7.4±1.0
N^{bkg}, GL$_{\mathrm{KS}}$ bin 3	1.5±0.4
N^{bkg}, GL$_{\mathrm{KS}}$ bin 4	$0.08^{+0.1}_{-0.05}$
Background GL$_{\mathrm{KS}}$ *p.d.f.* for $B^0 \to \mu^+\mu^-$	
N^{bkg}, GL$_{\mathrm{KS}}$ bin 1	351.6±6.6
N^{bkg}, GL$_{\mathrm{KS}}$ bin 2	8.3±1.0
N^{bkg}, GL$_{\mathrm{KS}}$ bin 3	1.9±0.4
N^{bkg}, GL$_{\mathrm{KS}}$ bin 4	$0.12^{+0.1}_{-0.07}$
Background Mass *p.d.f.* for B^0 and B_s^0	
k, GL$_{\mathrm{KS}}$ bin 1	$-(0.748 \pm 0.051)/$ GeV/c^2
k, GL$_{\mathrm{KS}}$ bin 2	$-(1.36 \pm 0.35)/$ GeV/c^2
k, GL$_{\mathrm{KS}}$ bin 3	$-(2.29 \pm 0.28)/$ GeV/c^2
k, GL$_{\mathrm{KS}}$ bin 4	$-(4.15 \pm 0.91)/$ GeV/c^2

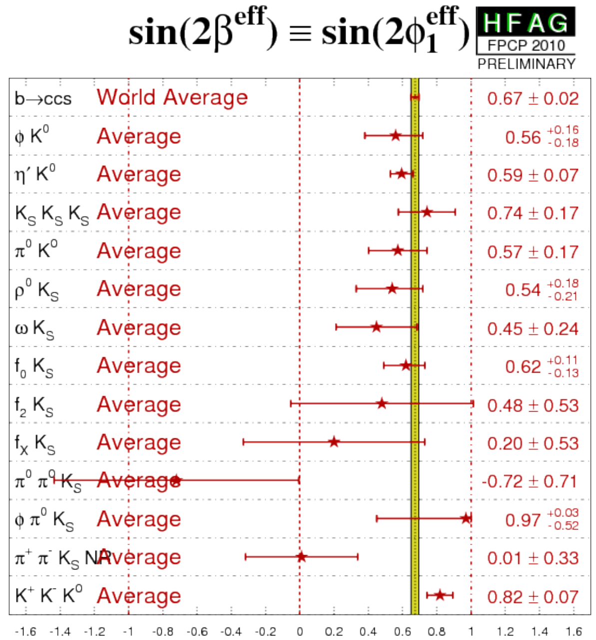
CP violation in charmless hadronic decays

Study of CPV $B_s \to \Phi\Phi$ and K^*K^* gives high sensitivity to NP, and will elucidate the B-factory 'sin2β_{eff} anomaly' (even though we will be working with B_s mesons...)

P. Cartelle, A. Suarez



Very promising prospects. $B_s \to K^*K^*$ first evidence/ observation in 2010 data!



Existing experiment with 4 fb^{-1} will achieve ~0.09 stat precision on CPV in $B_s \to \Phi\Phi$, which is similar to uncertainty on best B-factory mode ($B^0 \to \eta' K^0$). Upgrade is needed to do better! 50 fb^{-1} will give uncertainty ~ theoretical precision

Other important, LHCb unique, studies: multibody B_s decays e.g. $B_s \to K_S\pi\pi$, $K_SK\pi$

All benefit greatly from increased data samples and software trigger

New physics in a^s_{sl} (&/or a^d_{sl}) ?

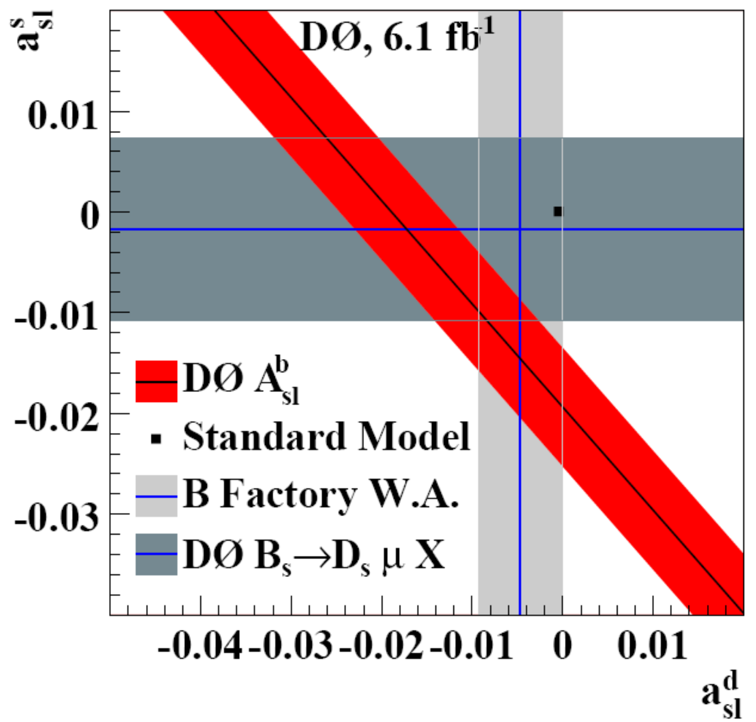
If New Physics enhances CP-violation in $B^0_S \to J/\psi\Phi$, it will likely also dominate over the (negligible) SM CP-violation predicted in the semi-leptonic asymmetry.

Recent D0 result shows 3σ discrepancy with SM (arXiv:1005.2757v1) using inclusive measurement of same-sign muon asymmetry A_b.

A_b is related to a^d_{fs} and a^s_{fs} :

$$A_b = (0.493 \pm 0.043)\, a^s_{fs} + (0.506 \pm 0.043)\, a^d_{fs}$$

where the coefficients are calculated using the production fractions measured at Tevatron [PLB 667,1 (2008)].



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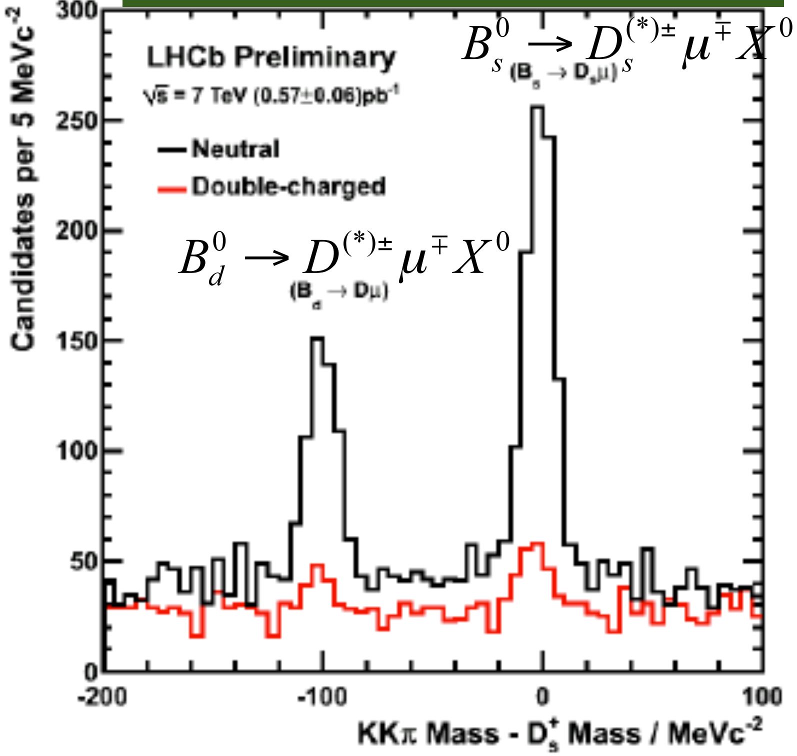
Inclusive method at LHCb is difficult due to the $\sim 10^{-2}$ production asymmetry in pp collisions and control of detector asymmetry.

LHCb will measure $a^s_{sl} - a^d_{sl}$, by determining the difference in the asymmetry measured in $B_s \to D_s(KK\pi)\mu\nu$ and $B^0 \to D^+(KK\pi)\mu\nu$:

→ difference suppresses production asymmetry

→ same final state suppresses detector biases.

First signals from 570 nb^{-1}



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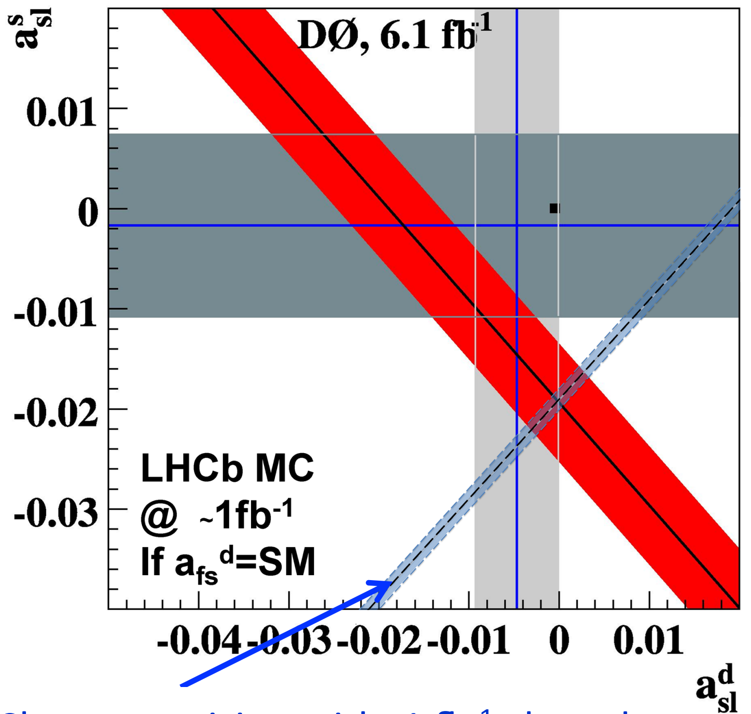
Inclusive method at LHCb is difficult due to the $\sim 10^{-2}$ production asymmetry in pp collisions and control of detector asymmetry.

LHCb proposes to measure $a^s_{sl} - a^d_{sl}$, by determining the difference in the asymmetry measured in $B_s \to D_s(KK\pi)\mu\nu$ and $B^0 \to D^+(KK\pi)\mu\nu$:

→ difference suppresses production asymmetry

→ same final state suppresses detector biases.

This method provides orthogonal constraint to D0 di-leptons.



LHCb stat precision with 1 fb^{-1} plotted for D0 central value & no NP in a^d_{sl}