LHCb physics results

Marie-Hélène SCHUNE
LAL-Orsay
LHCb collaboration

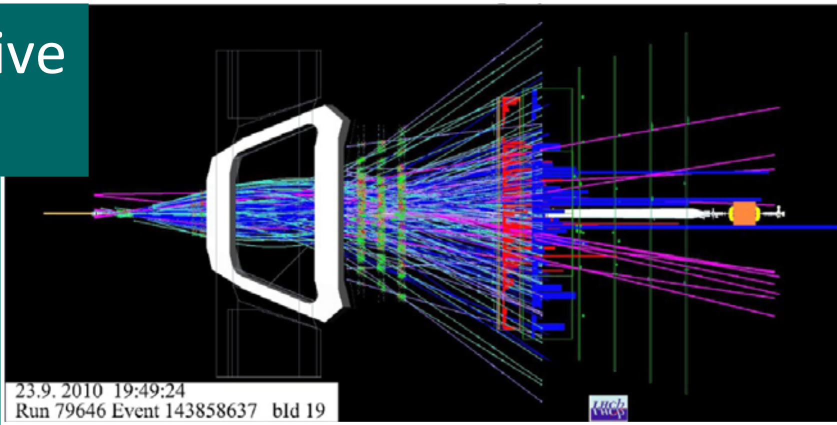
- Introduction : b physics and LHCb

μ in the decay products

- $B_{(s)} \rightarrow \mu\mu$
- $B \rightarrow K^*\mu\mu$
- Search for physics beyond SM in B_s mixing or CP

Hadronic/radiative decay

- $B \rightarrow K^*\gamma$ and $B_s \rightarrow \varphi\,\gamma$
- Hadronic decays : measurement of the UT angle $\gamma\,/\varphi_3$



Slides borrowed from : Tim Gershon, Wouter Hulsbergen, Gerard Raven, Guy Wilkinson

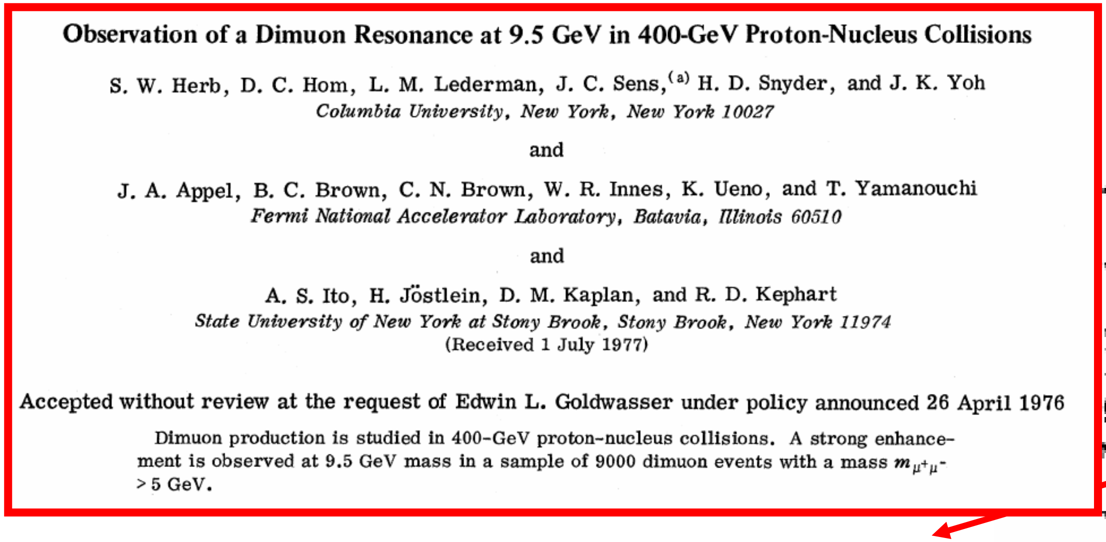
- Introduction : b physics and LHCb

- $B_{(s)} \rightarrow \mu\mu$
- $B \rightarrow K^*\mu\mu$
- Search for physics beyond SM in B_s mixing or CP

- B-> $K^*\gamma$ and B_s->Phi γ
- Hadronic decays : Measurement of the UT angle γ / φ_3

1977 : b quark discovery

9.5-10.5 GeV : The series of Υ



Observation of a Dimuon Resonance at 9.5 GeV in 400-GeV Proton-Nucleus Collisions

S. W. Herb, D. C. Hom, L. M. Lederman, J. C. Sens,(a) H. D. Snyder, and J. K. Yoh
Columbia University, New York, New York 10027

and

J. A. Appel, B. C. Brown, C. N. Brown, W. R. Innes, K. Ueno, and T. Yamanouchi
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

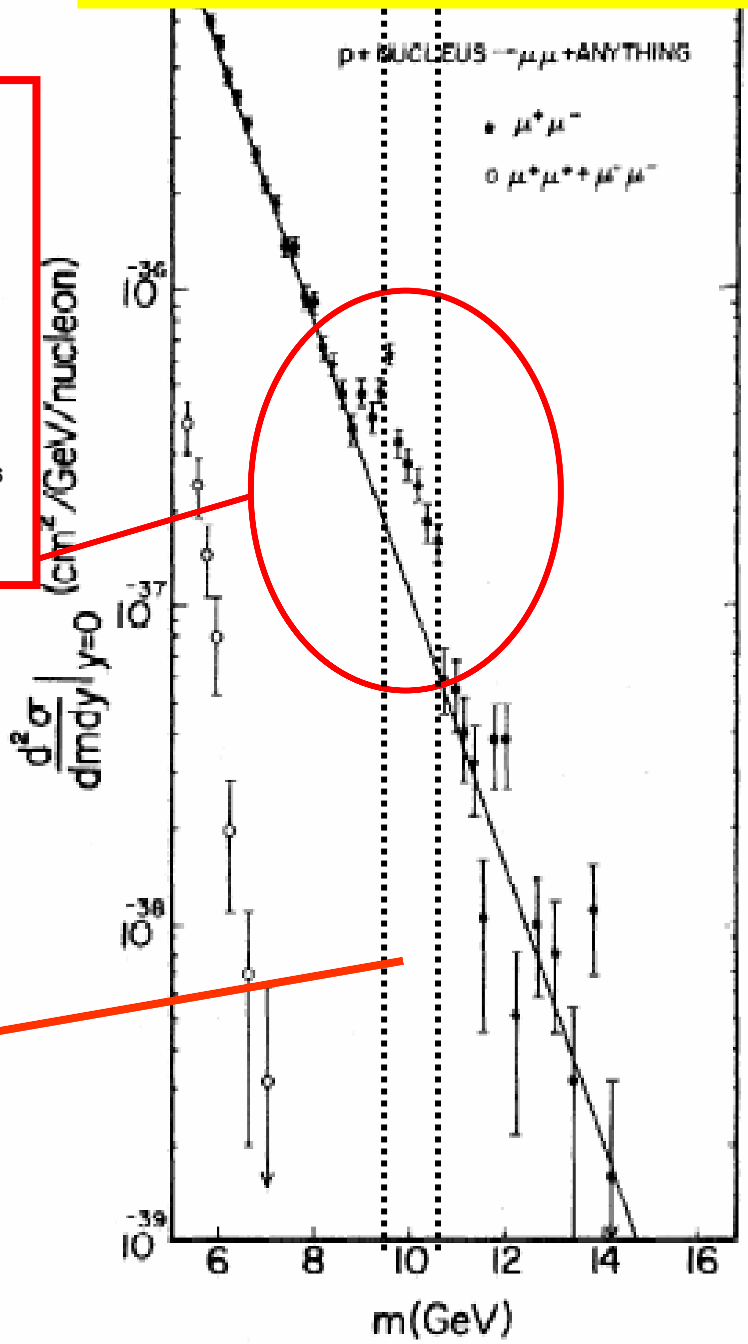
and

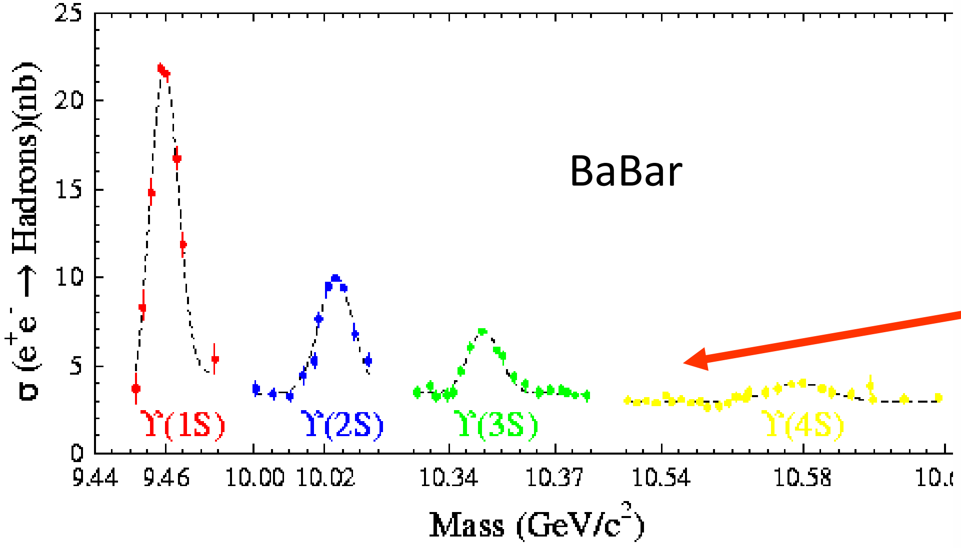
A. S. Ito, H. Jöstlein, D. M. Kaplan, and R. D. Kephart
State University of New York at Stony Brook, Stony Brook, New York 11974

(Received 1 July 1977)

Accepted without review at the request of Edwin L. Goldwasser under policy announced 26 April 1976

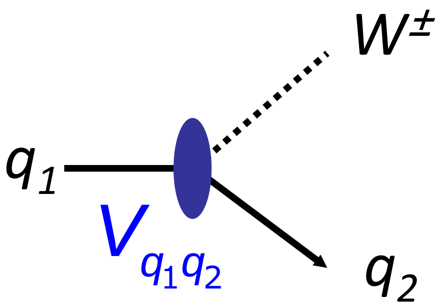
Dimuon production is studied in 400-GeV proton-nucleus collisions. A strong enhancement is observed at 9.5 GeV mass in a sample of 9000 dimuon events with a mass $m_{\mu^+\mu^-} > 5$ GeV.





Why B physics ?

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



Weak eigenstates ≠ Mass eigenstates

$$\begin{pmatrix} u & c & t \end{pmatrix} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

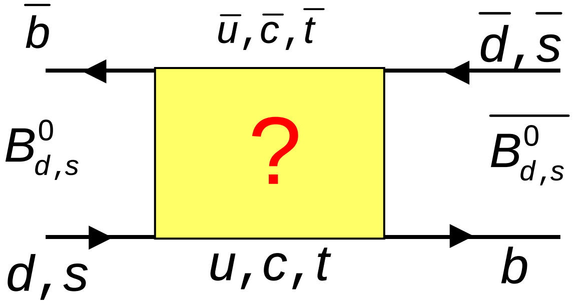
$$\boxed{\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \vartheta\left(\lambda^4\right)}$$

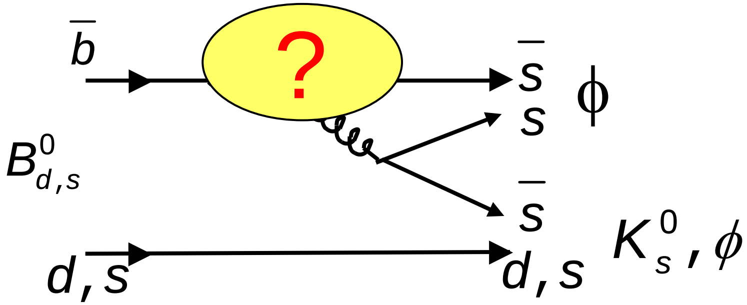
SM does not predict the value of the CKM matrix elements

CKM accounts for the CP violation, but doesn't really explain it

B hadrons :

- Many decays ↔ many observables
- Mixing phenomenon and CPV
- Many observables for which the SM don’t hide NP (ex: no CPV processes, suppression mechanism like loops, GIM-suppressed FCNC, etc..)
- Many different couplings to NP can be measured.
- Loop/boxes : NP part. can contribute even if too heavy for a direct observation.





Argus Collab: Phys. Lett. 192B (1987) 245

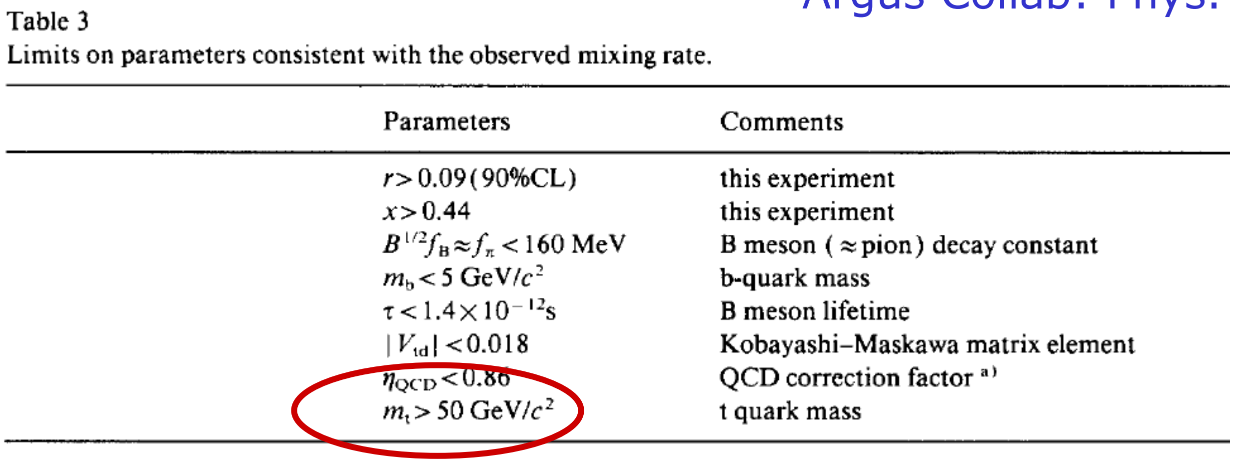


Table 3

Limits on parameters consistent with the observed mixing rate.

Parameters	Comments
$r > 0.09$ (90%CL)	this experiment
$x > 0.44$	this experiment
$B^{1/2} f_B \approx f_\pi < 160$ MeV	B meson (≈ pion) decay constant
$m_b < 5$ GeV/c^2	b-quark mass
$\tau < 1.4 \times 10^{-12}$s	B meson lifetime
$\lvert V_{td} \rvert < 0.018$	Kobayashi–Maskawa matrix element
$\eta_{QCD} < 0.86$	QCD correction factor [a)]
$m_t > 50$ GeV/c^2	t quark mass

NP ? A lot of choices .. !

- Various realizations of SUSY : *(MFV-)MSSM, generic + mass insertion, mSugra, GUT, w/ or w/o R-parity, etc…*
- Little Higgs Model
- 4-th generation
- …

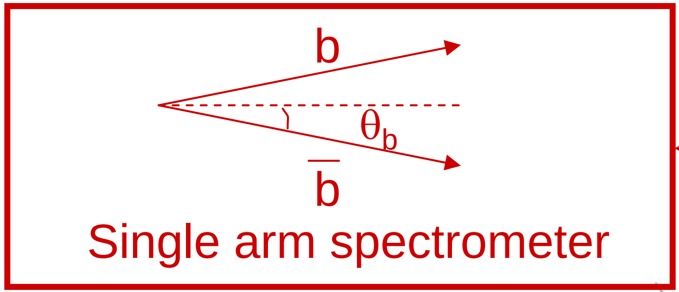
Effective theory : a game with scale and couplings

$$\frac{\left|\delta_{bq}\right|}{\Lambda_{\mathrm{eff}}^{2}}$$

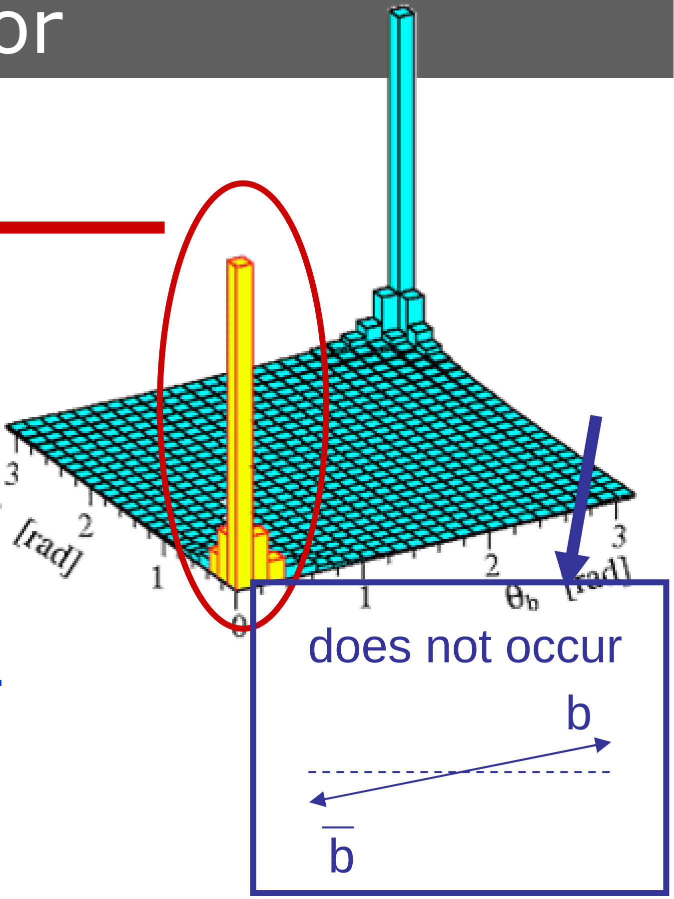
Flavour structure of the theory

Scale of the NP (=mass of the new particles)

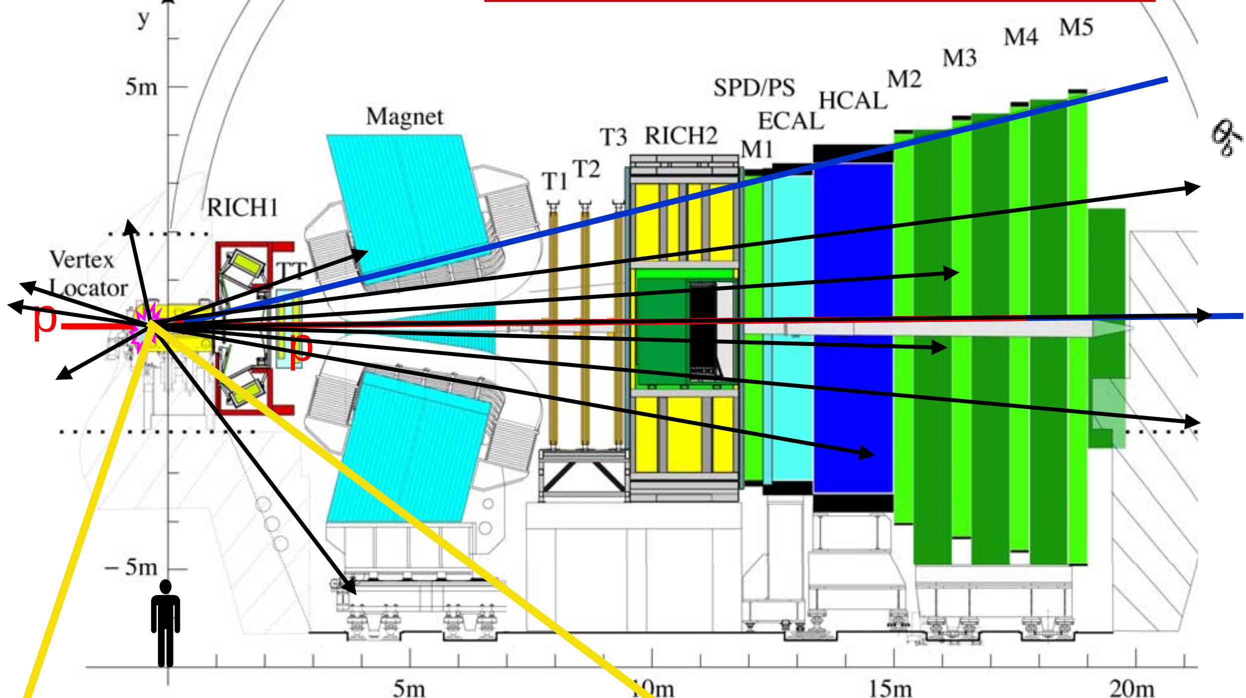
The LHCb detector

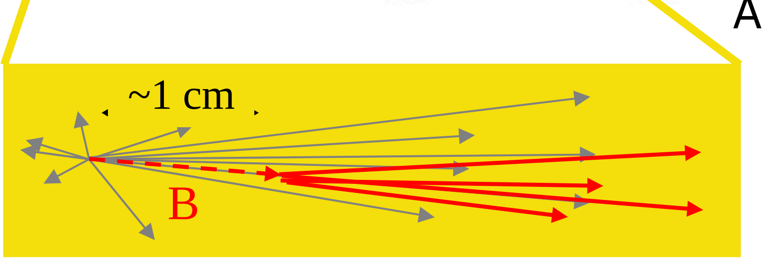


Single arm spectrometer



does not occur

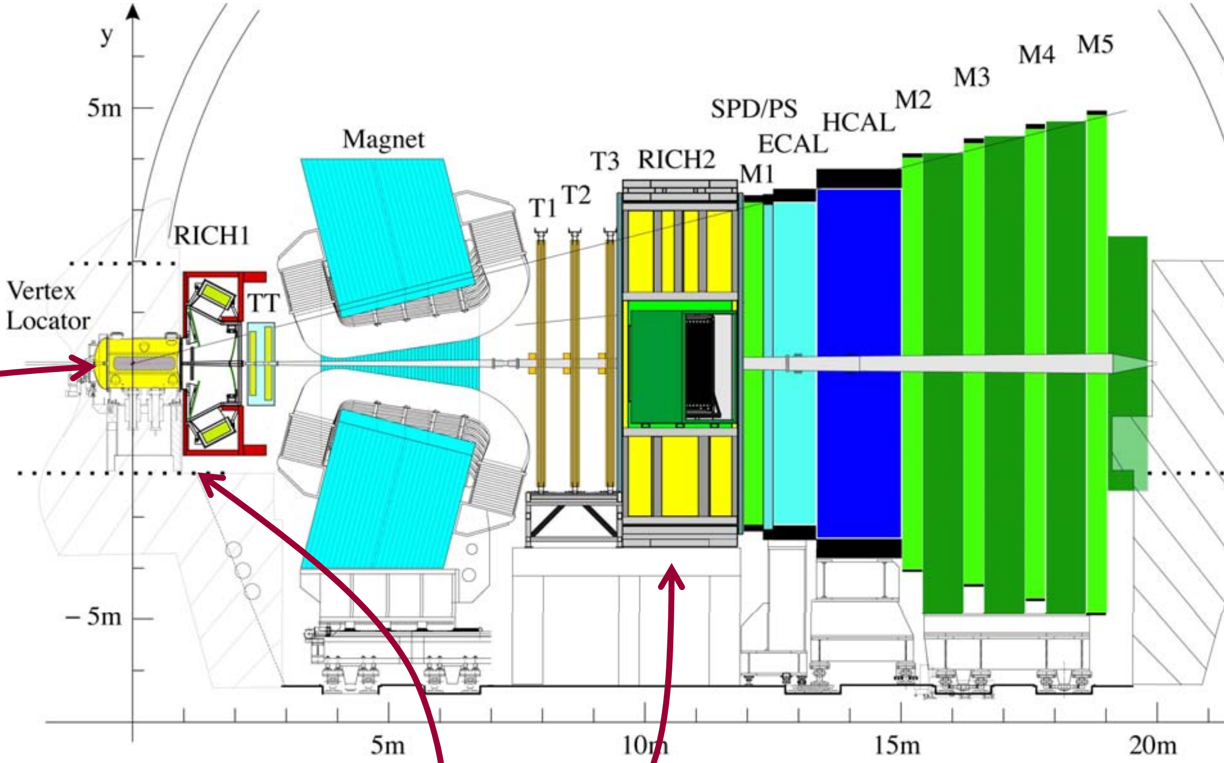




Acceptance : ~ 10 to 300 mrad

15% of σ_{bb} with both b in LHCb acceptance
⇒ need for an efficient trigger

$b\bar{b}$ cross-section = 284 ± 53 μb at the LHC
(pp collisions at √s = 7 TeV) [PLB **694** 209]

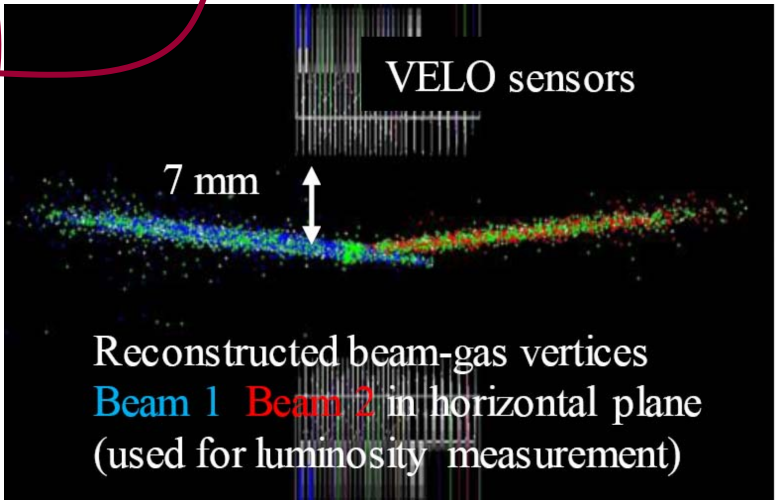


- Very precise vertexing
  - vertex detector : 8mm from beam
  - Vertex detector is retracted during injection

- p/K/π identification
  - 2 RICH detectors : separation up to 100 GeV

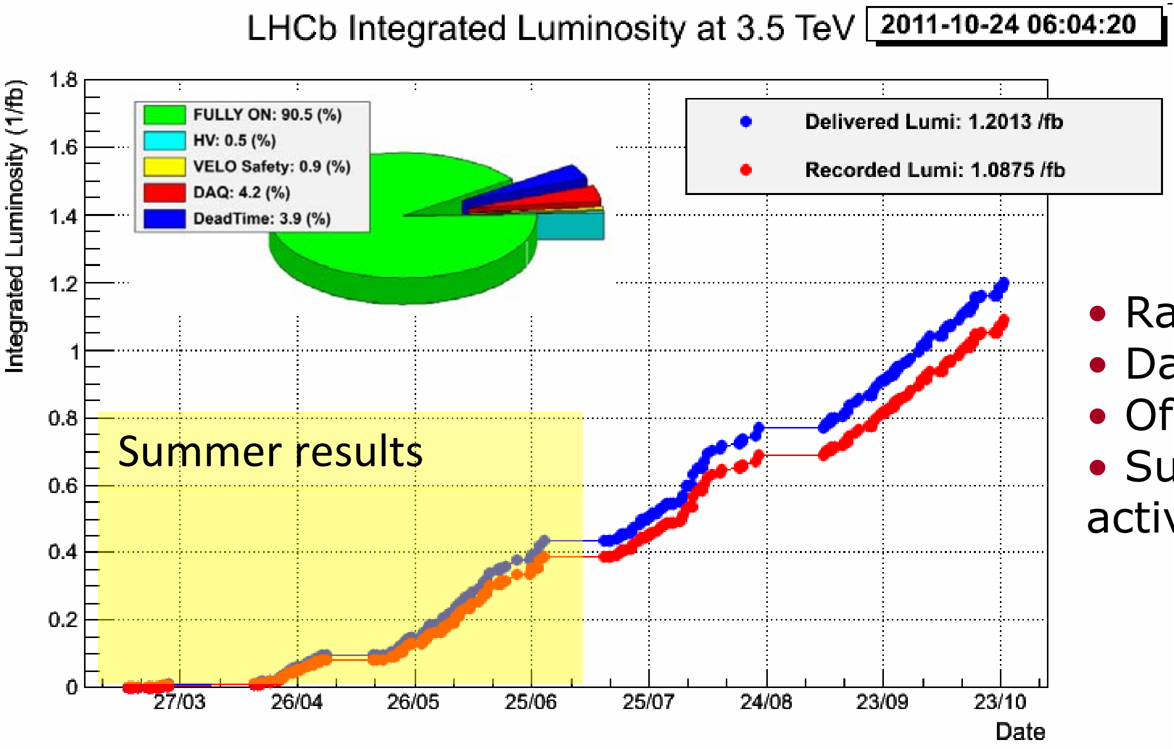
- Excellent momentum resolution

- dedicated heavy flavour trigger
  - L0 : hardware trigger : high pT hadrons and leptons : **1MHz**
  - HLT flexible software trigger (full tracking and vertexing) : **3 kHz**



Reconstructed beam-gas vertices
Beam 1 Beam 2 in horizontal plane
(used for luminosity measurement)

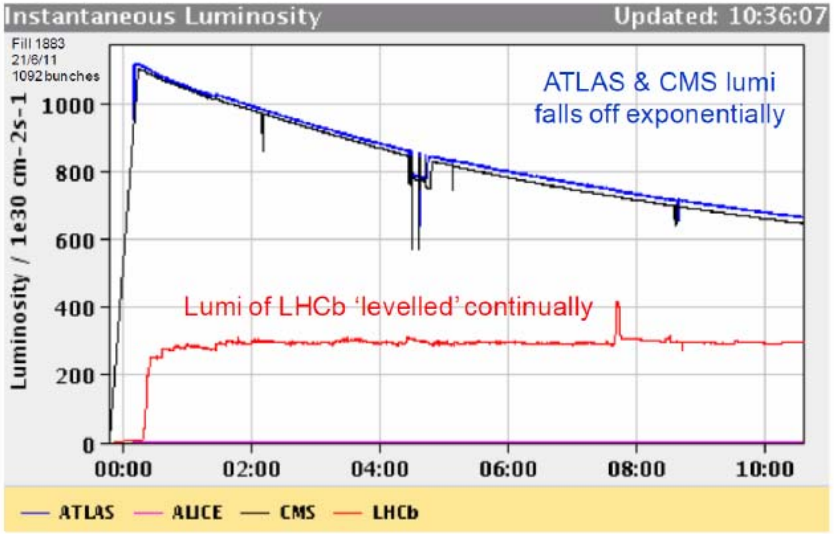
2011 : integrated luminosity



- Rapid increase of the luminosity
- Data taking efficiency > 90%
- Offline data quality rejects < 1%
- Sub-detectors all with > 98% active channels

•LHCb reconstruction/trigger efficiency sensitive to pileup (design : 2 10^{32} cm^{-2} s^{-1})

•Continuous (automatic) adjustment of offset of colliding beams allows luminosity to be leveled

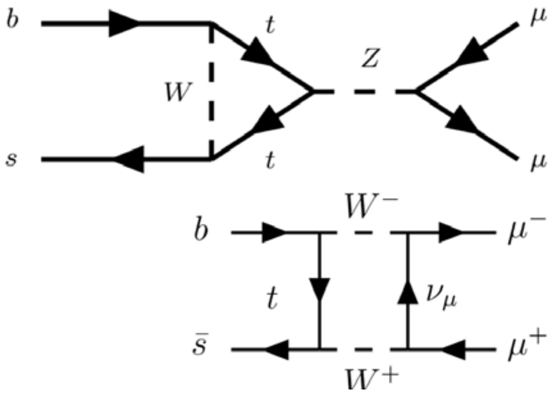


- Short introduction

- $B_{(s)} \rightarrow \mu\mu$
- $B \rightarrow K^*\mu\mu$
- Search for physics beyond SM in B_s mixing or CP

- B-> $K^*\gamma$ and B_s->Phi γ
- Hadronic decays
  - Measurement of the UT angle γ / φ_3
  - Charmless decays

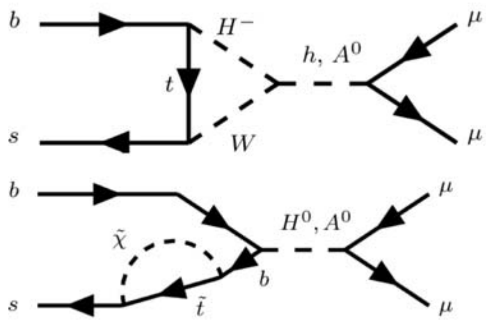
$B_s \rightarrow \mu\mu$



SM

SM : very rare (GIM and helicity suppression)

$$\mathrm{Br}_{\mathrm{SM}}(B_s \rightarrow \mu\mu) = (3.2\pm0.2) \times 10^{-9}$$



NP

Large sensitivity to NP, eg:

$$\mathrm{Br}_{\mathrm{MSSM}}(B_q \rightarrow \ell^+\ell^-) \propto \frac{M_b^2 M_\ell^2 \tan^6\beta}{M_A^4}$$

- Search for a very rare signal at hadron colliders (Tevatron and LHC)
- Sophisticated analyses
- Look for signal in bins of NN and invariant mass
- A lot of efforts put on using as much as possible data instead of MC
- Blind analyses
- Search for B_d and B_s (B_d even smaller in SM) : would help to disentangle NP models (both BR changed differently in leptoquarks models …)

Analysis strategy :

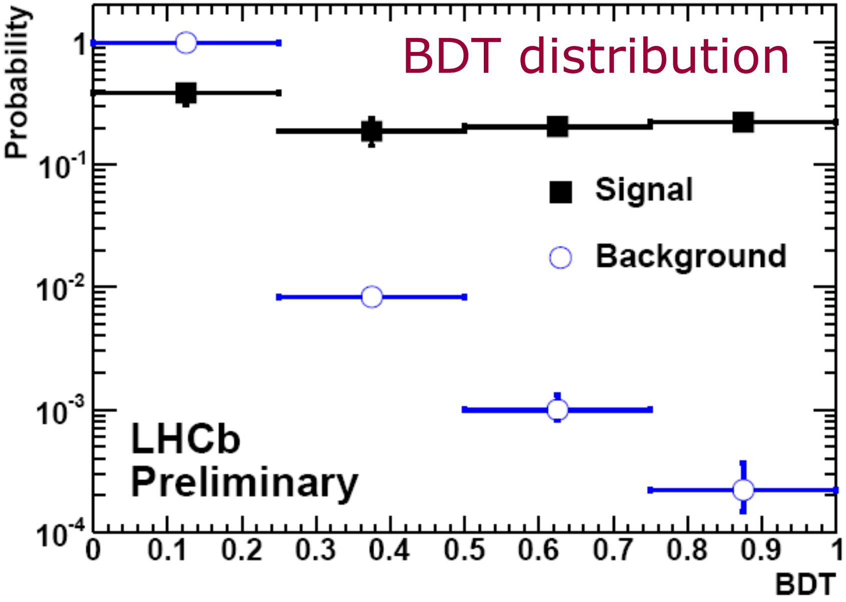
- Soft selection

- Discrimination between signal and background Boosted Decision Tree and B mass
    - BDT combining 9 topological and kinematical observables
    - BDT calibrated on B →hh (signal) and B mass sidebands (background)
    - 2D plane (4 BDT bins, 6B mass bins)

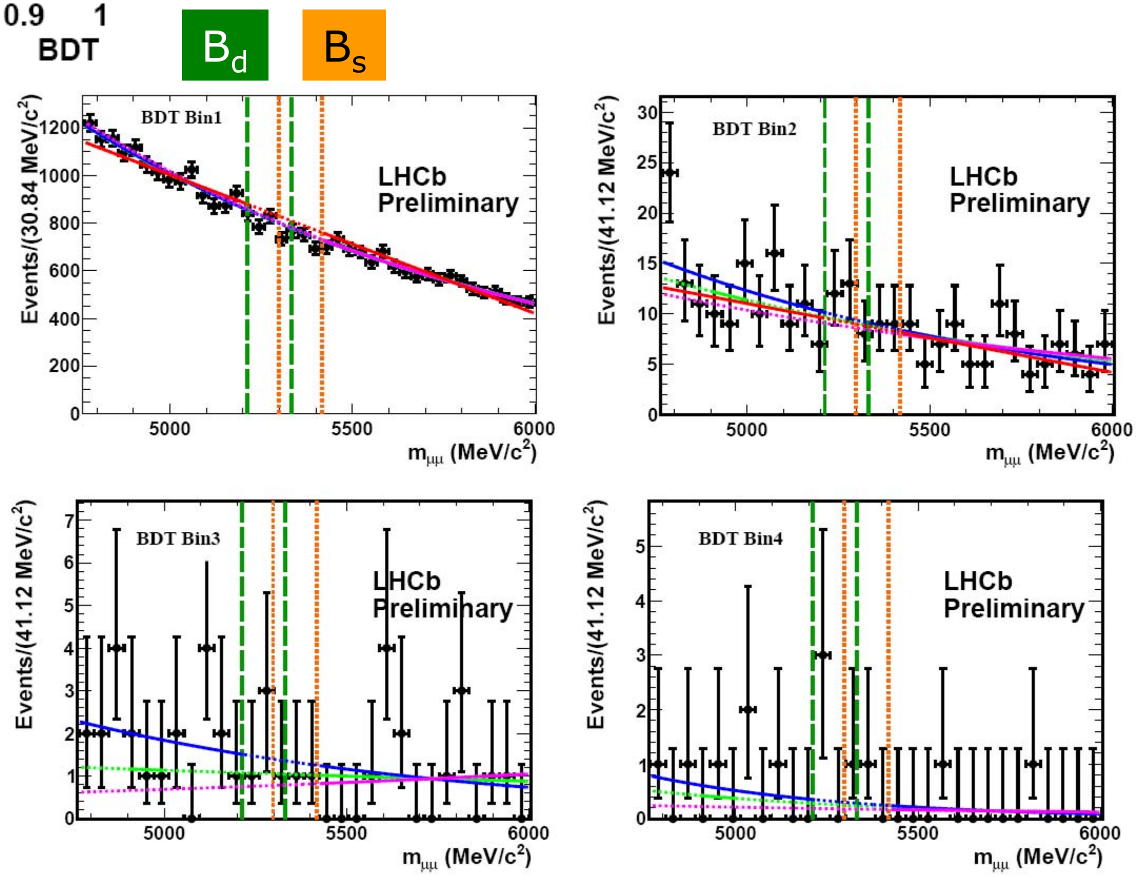
- Mass resolution :
    - Interpolation between J/ψ→ μ μ and Υ→ μ μ
    - checked using $B_{d,s}\rightarrow hh$

- Normalization for BR extraction
    - compare S with yields of events from known BR ($B_d\rightarrow J/\psi K$, $B_s\rightarrow J/\psi\ \varphi$, $B_d\rightarrow hh$)
    - use f_d/f_s from LHCb combined result ($.267\ ^{+0.021}_{-0.020}$)

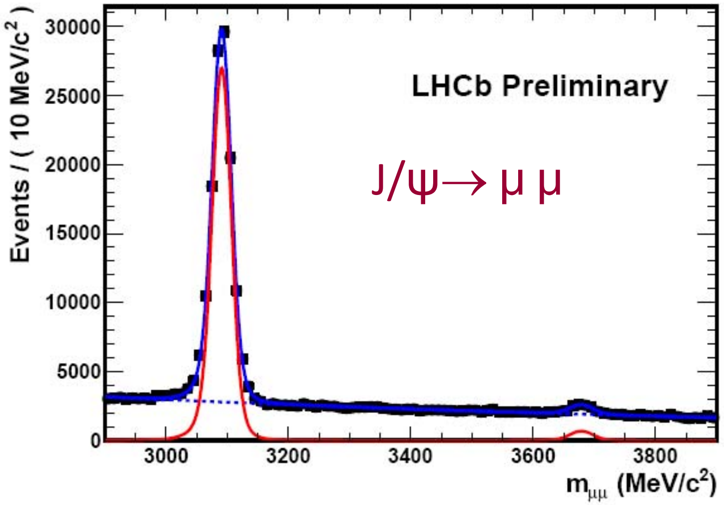
- Extraction of the limit :
    - assign to each observed event a probability to be S+B or B-only as a function of the BR($B_{d,s}\rightarrow \mu\mu$) value
    - exclude (or observe!) the assumed BR value at a given Confidence Level value using the CLs binned method

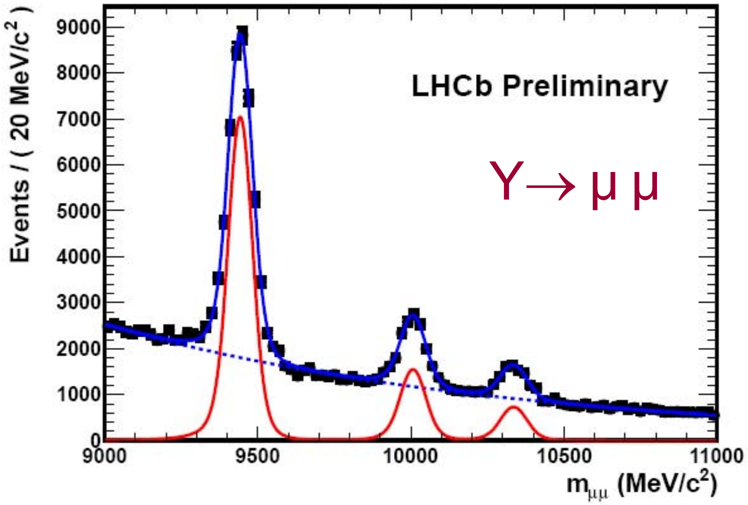


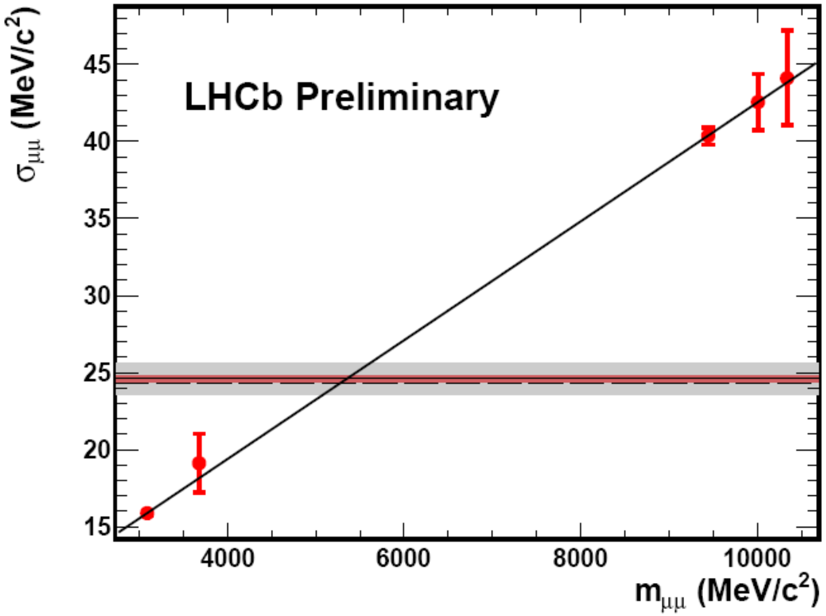
B invariant mass distribution :



B invariant mass resolution :







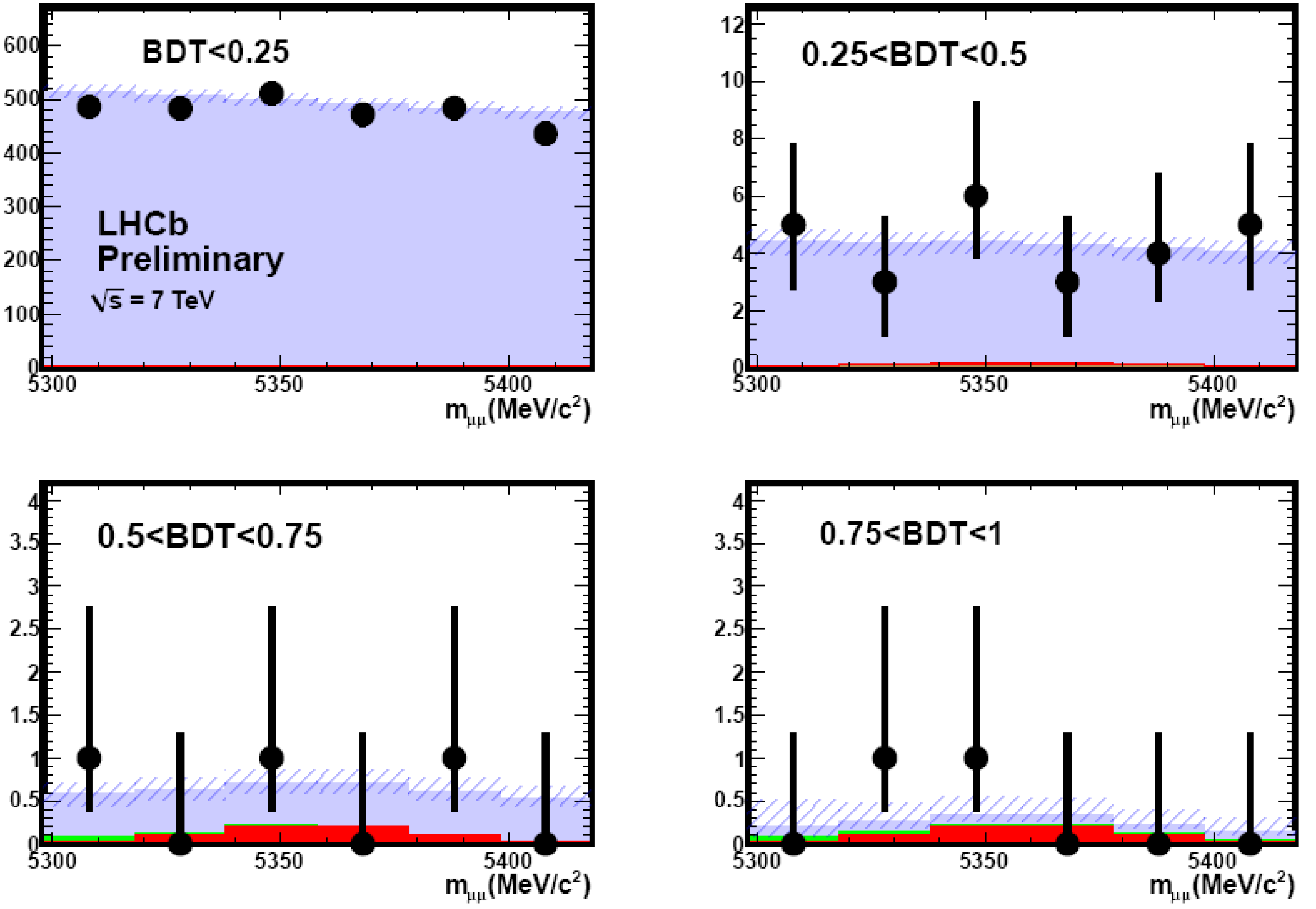
method	$\sigma(B_s^0)$ (MeV/c^2)
interpolation	$24.6 \pm 0.2_{\text{stat}} \pm 1.0_{\text{syst}}$
$B^0_{(s)} \to h^+h^-$ inclusive	$23.7 \pm 0.4_{\text{stat}} \pm 1.5_{\text{syst}}$
$B^0_{(s)} \to h^+h^-$ exclusive	$23.5 \pm 0.2_{\text{stat}} \pm 1.3_{\text{syst}}$

Data

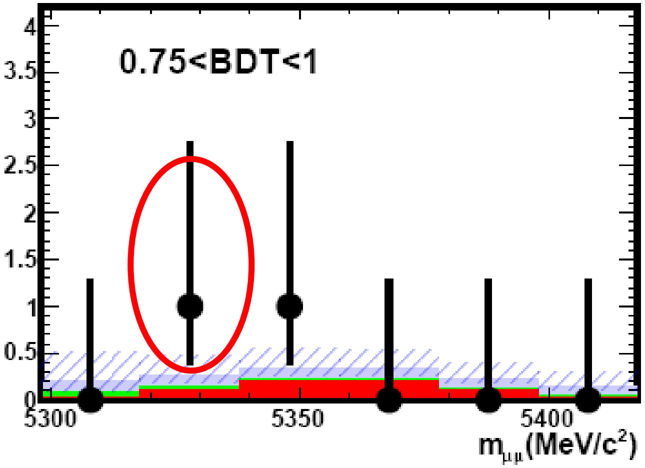
Combinatorial background

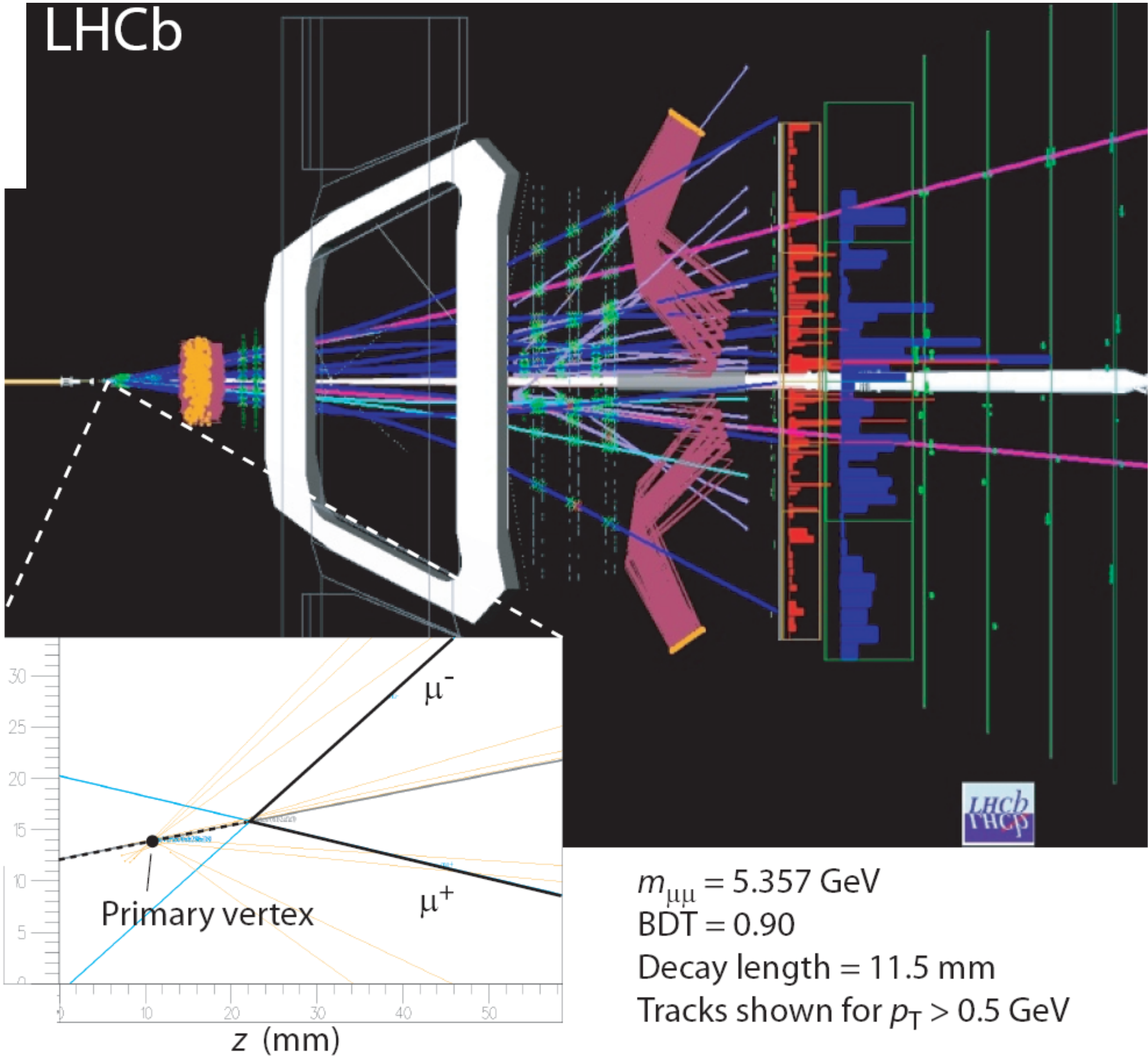
B→hh misId background

Signal (SM BF)

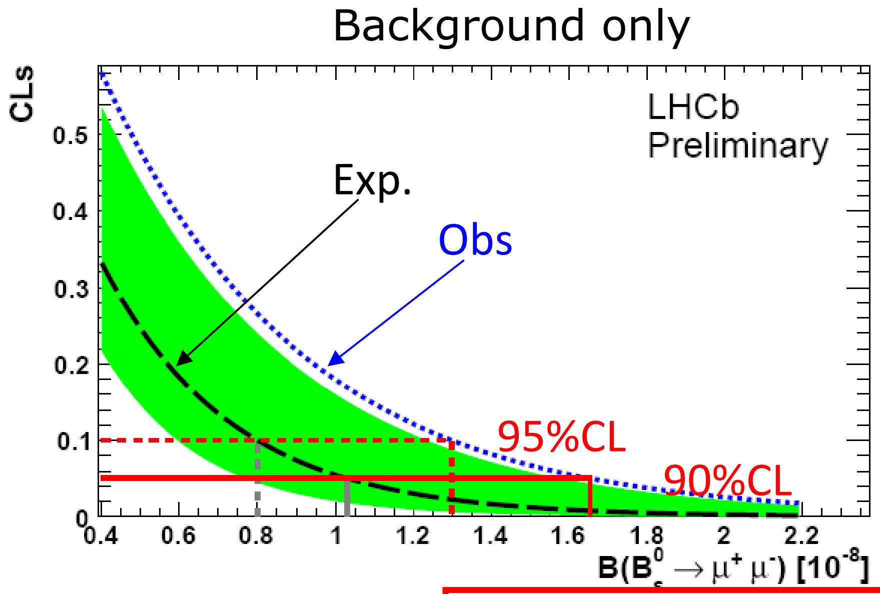


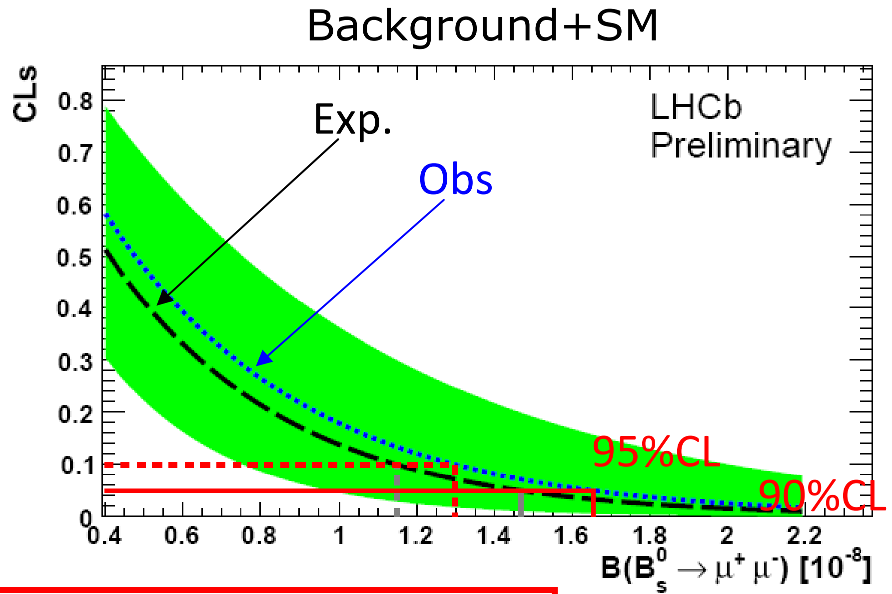
	BDT<0.25	0.25<BDT<0.5	0.5<BDT<0.75	0.75<BDT
Exp.combinatorial	2968 ± 69	25 ± 2.5	2.99 ± 0.89	0.66 ± 0.40
Exp. SM signal	1.26 ± 0.13	0.61 ± 0.06	0.67 ± 0.07	0.72 ± 0.07
Observed	2872	26	3	2





$m_{\mu\mu} = 5.357$ GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for $p_T > 0.5$ GeV



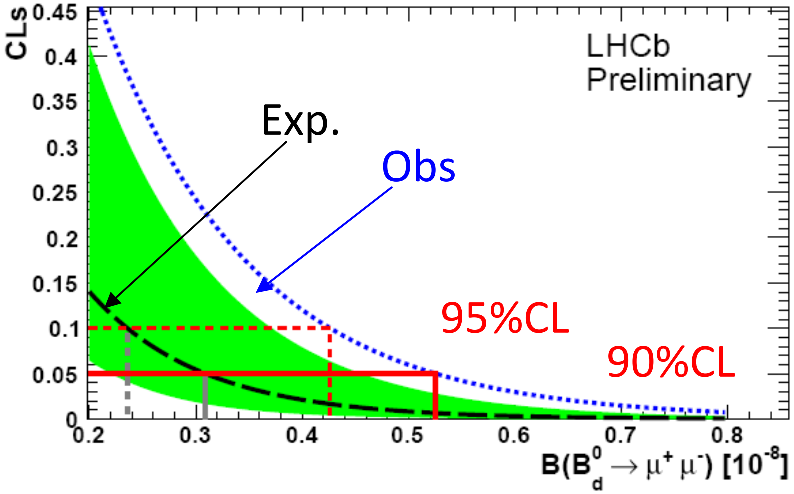


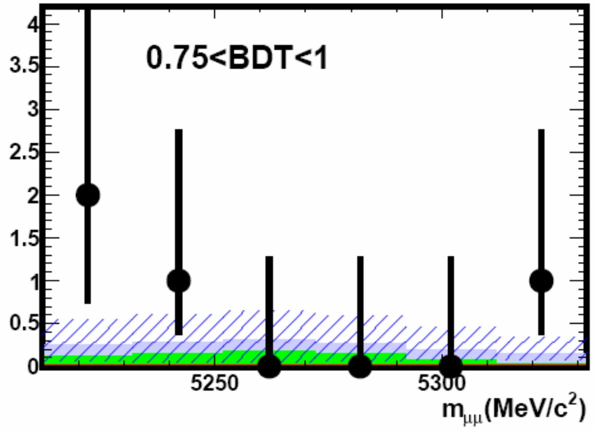
B_s

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) \; < \; 1.3(1.6) \times 10^{-8} \text{ at } 90\,\%(95\,\%) \text{ C.L.},$$

B_d

$$\mathcal{B}(B^0 \to \mu^+\mu^-) \; < \; 4.2(5.1) \times 10^{-9} \text{ at } 90\,\%(95\,\%) \text{ C.L.}$$





CMS and LHCb (2010+2011) combined result :

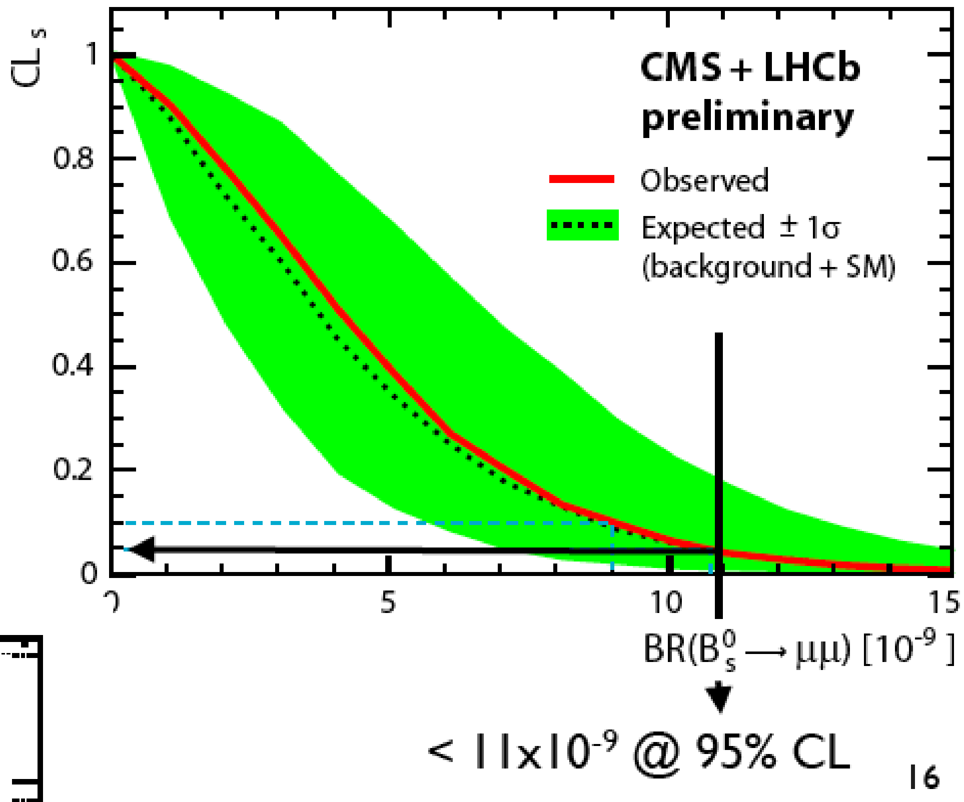
$$\left(\frac{f_s}{f_d}\right)_{LHCb} = 0.267^{+0.021}_{-0.020}$$

p value (Bkgd only) : 8%

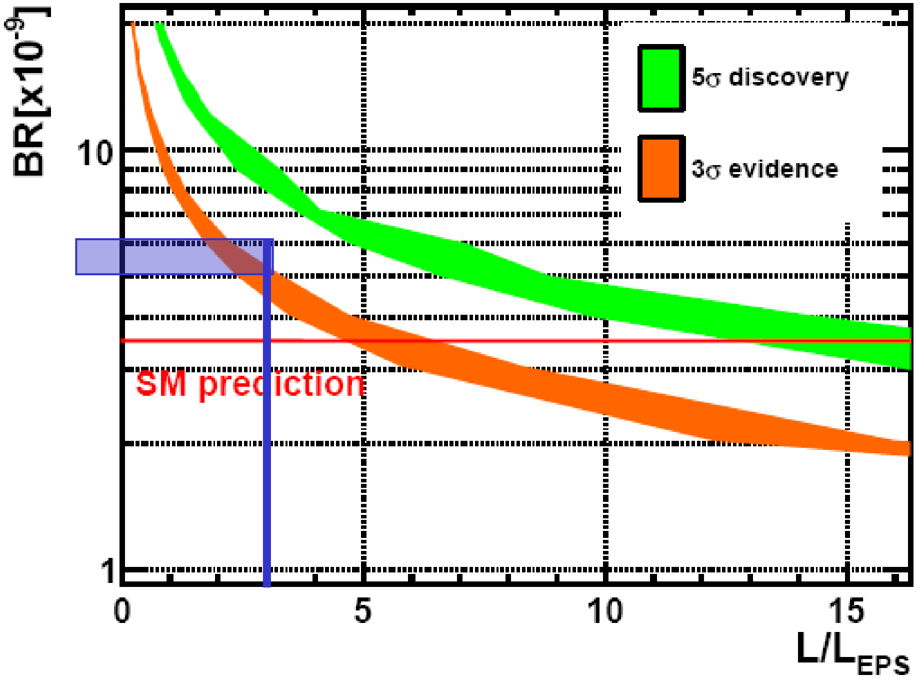
p value (Bkgd +SM) : 55 %

BR($B_s \to \mu\mu$) < 11 10^{-9} @ 95 % CL

(about 3.4 x SM)



arXiv:1108.3018v1



LHCb-CMS combined could claim a 3σ evidence if BR=(5-6)x10^{-9} by 2012 winter conferences

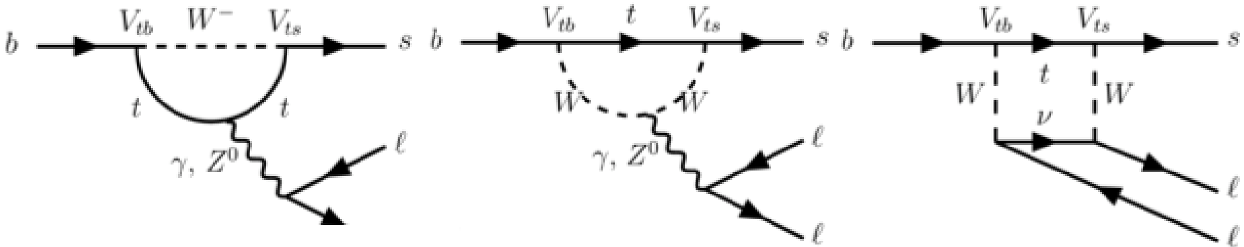
~1 fb-1 for LHCb, ~3.3 fb-1 for CMS

- Introduction : b physics and LHCb

- $B_{(s)} \rightarrow \mu\mu$
- $B \rightarrow K^{*}\mu\mu$
- Search for new physics in B_s mixing or CP

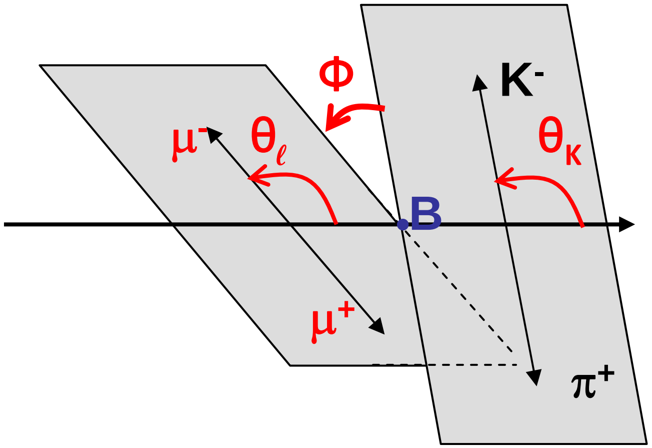
- $B \rightarrow K^{*}\gamma$ and $B_s \rightarrow \varphi\ \gamma$
- Hadronic decays : measurement of the UT angle γ /φ_3

B→K*μμ



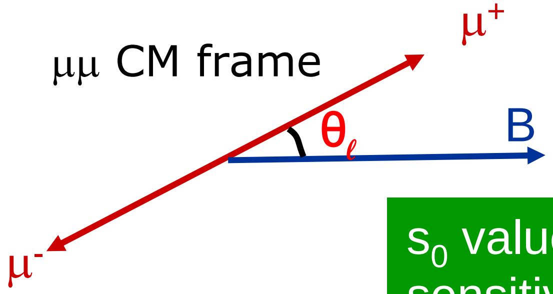
- Flavour changing neutral current decay :
  BR = (3.3 ±1.0) 10^{-6}

- System described by
  - Invariant mass squared of the dimuon system q^2
  - 3 angles to describe the decay



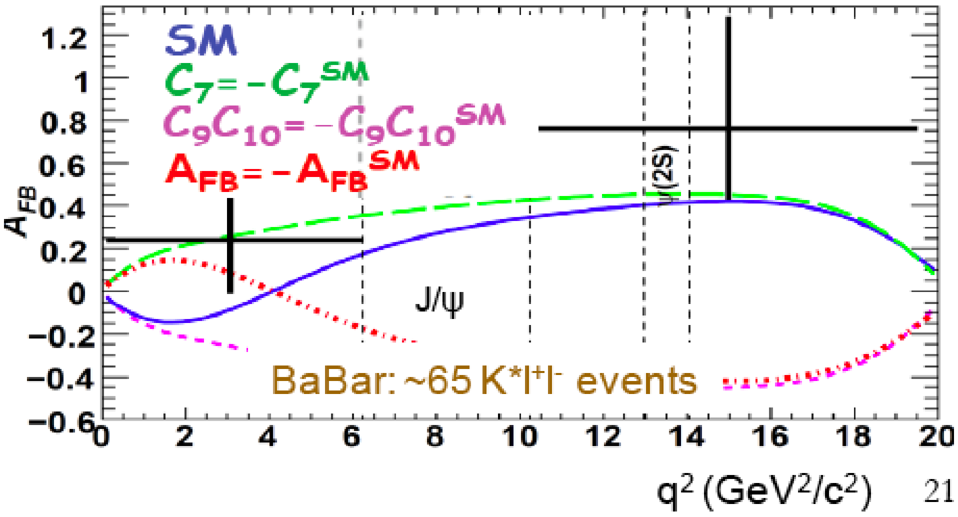
- Probe of the helicity structure of BSM physics
- First measurement : A_{FB} as function of q^2

$$A_{FB} = \frac{\Gamma(\cos\theta_{B\ell^+} > 0) - \Gamma(\cos\theta_{B\ell^+} < 0)}{\Gamma(\cos\theta_{B\ell^+} > 0) + \Gamma(\cos\theta_{B\ell^+} < 0)}$$



s_0 value
sensitive to NP

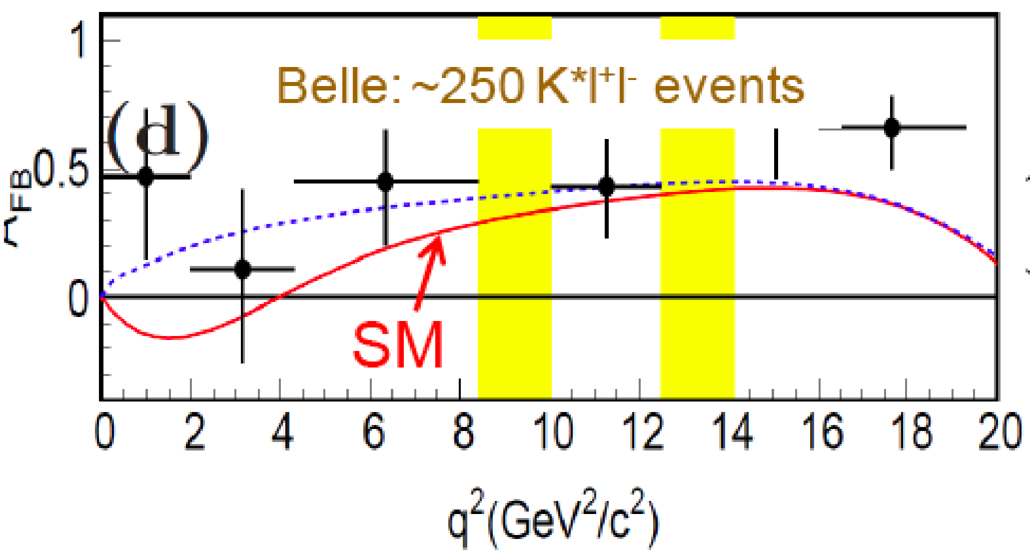
B_d (not B_s) meson : can be studied at B-Factories



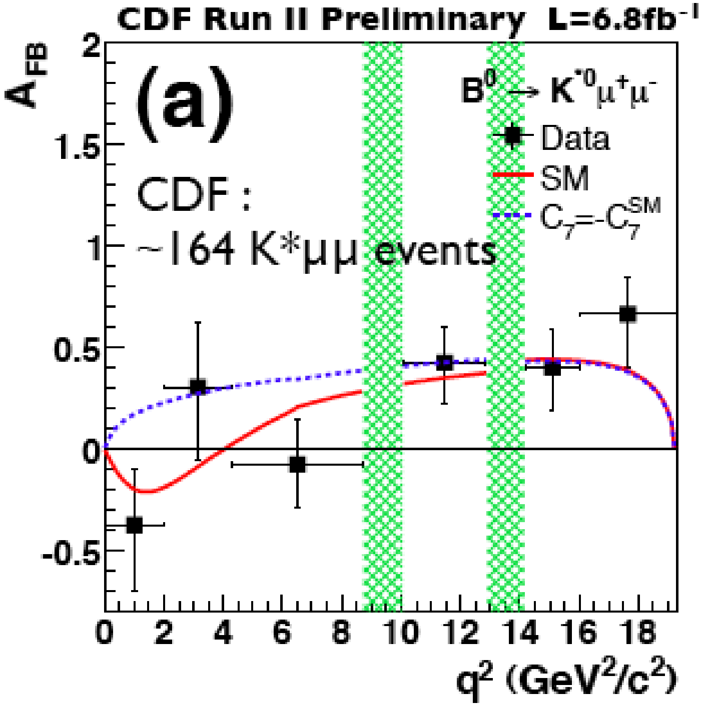
PRD 79 (2009) 031102

Low q^2 behaviour ?

CDF (EPS2011) : 6.8 fb-1



PRL 103 (2009) 171801



arXiv:1108.0695

$B_d \rightarrow K^*\mu\mu$ analysis strategy :

LHCb-CONF-2011-038

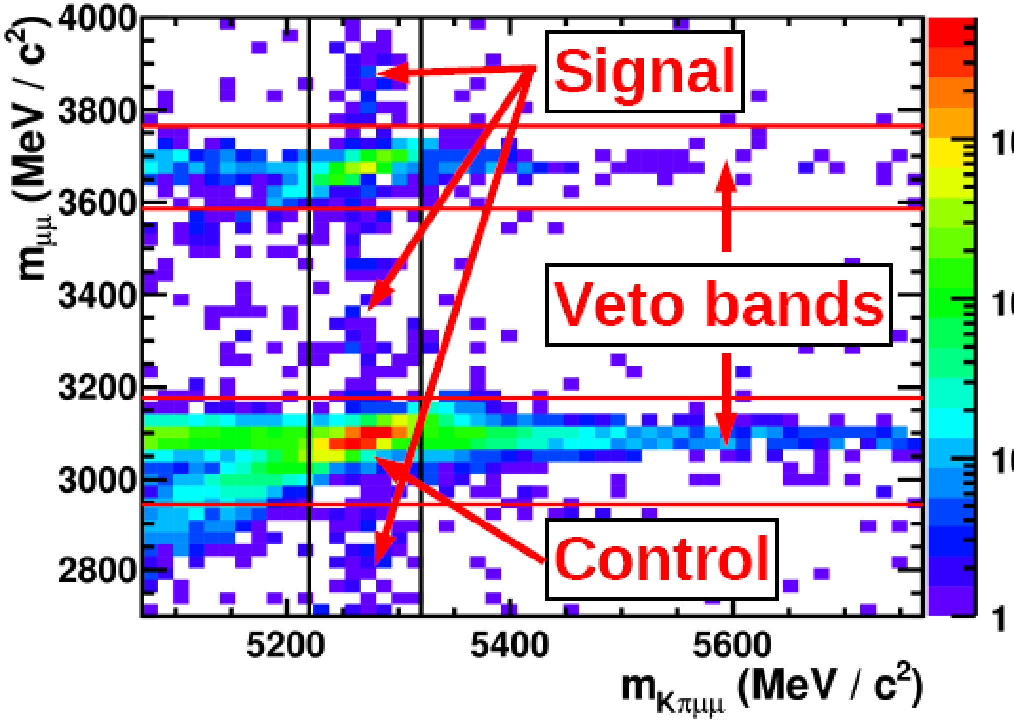
- Soft selection

- Event selection : Boosted Decision Tree
  - Trained on $B_d \rightarrow J/\psi K^{*0}$ (signal) and side-bands (background) from 2010 data
  - Variables chosen to minimize biases on angular acceptance : B kinematics, B0 vertex quality, daughter track quality, impact parameter and K, π and μ PID

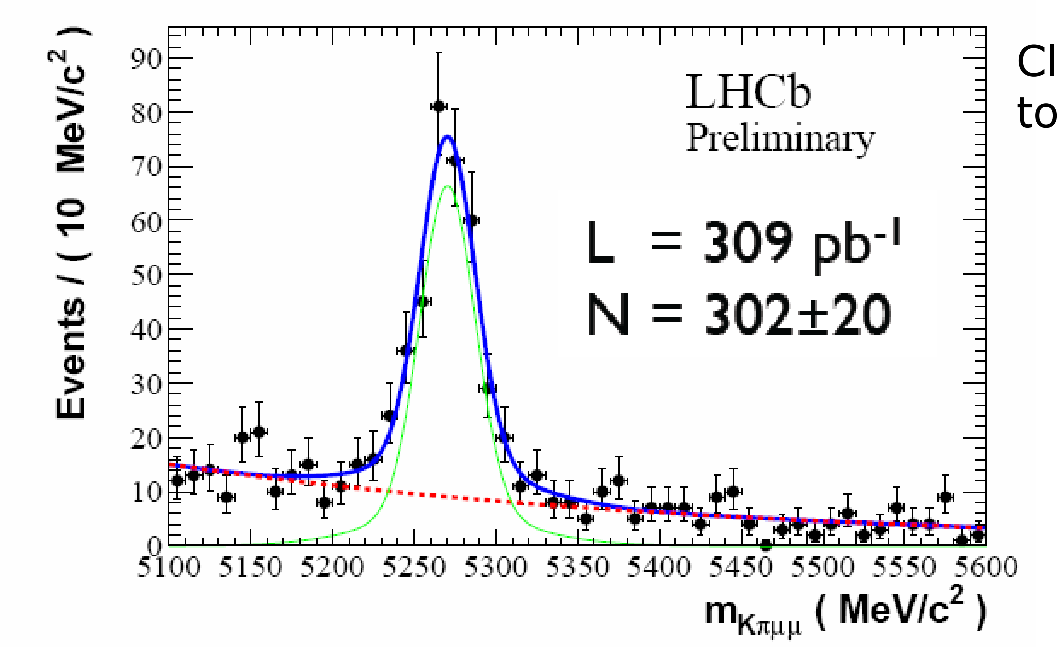
- Efficiency correction (angular acceptance) :
  - event by event correction

- Fit for observables :
  - simultaneous fit to the B mass and the angular distributions

- Analysis cross-check :
  - use the known $B_d \rightarrow J/\psi K^{*0}$ angular distribution



After the JPsi and Psi(2S) vetoes :



Clean signal, larger than CDF, similar to BELLE

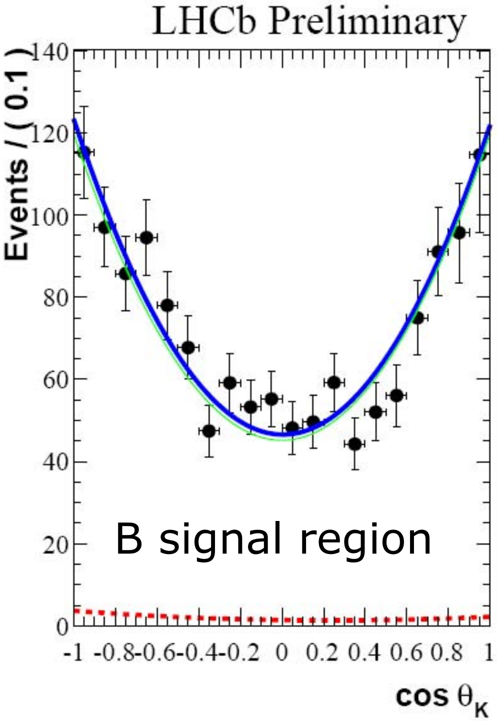
- Measure in 6 q^2 bins
  - differential BF $d\Gamma/dq^2$ normalized to the $B_d \to J/\psi K^{*0}$ known BF
  - longitudinal polarization F_L
  - A_{FB}
- simultaneous fit to 1D projections of θ_K and θ_ℓ and B mass

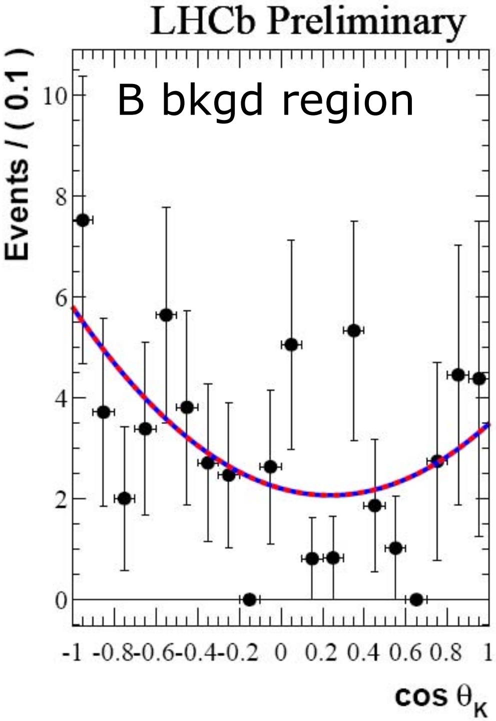
$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}q^2} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}\cos\theta_K\,\mathrm{d}q^2} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

Crosscheck on $B_d \rightarrow J/\psi K^{*0}$:

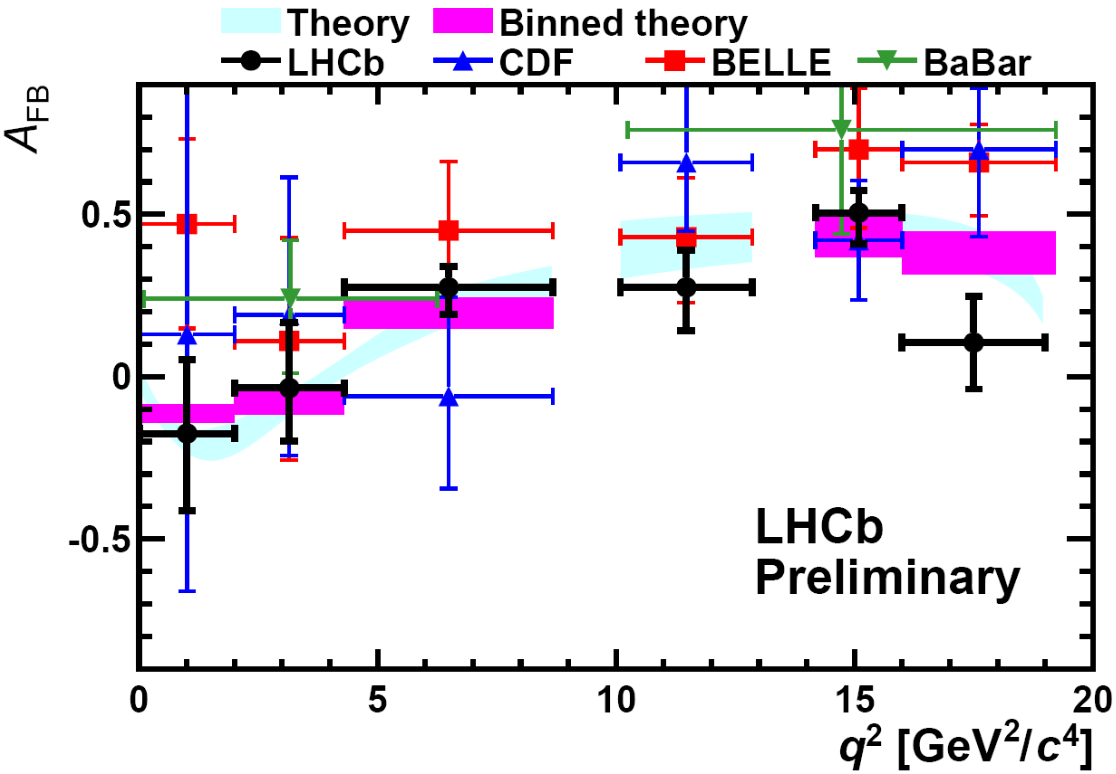
When including S-wave, result is in very good agreement with BaBar analysis

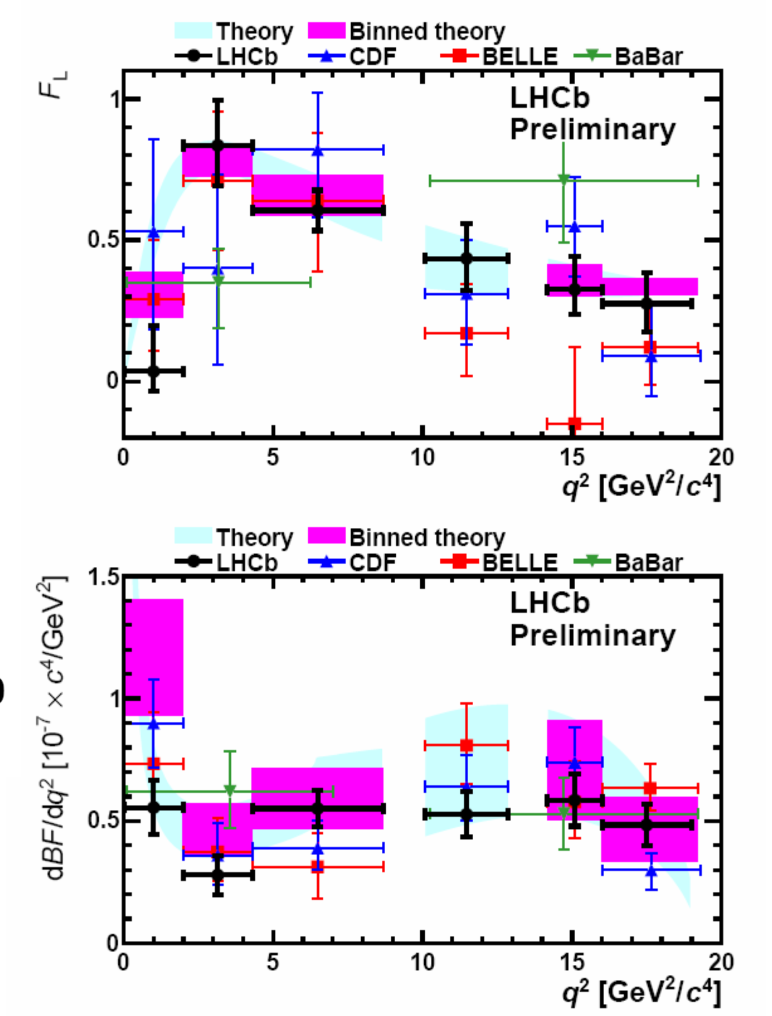




$900 < M(K\pi) < 980$ MeV

Results for A_{FB}, F_L and $d\Gamma/dq^2$:





LHCb: LHCb-CONF-2011-038
CDF: arXiv:1108:0695
BELLE: PRL103:171801,2009
BaBar: PRD73:092001,2006

- Introduction : b physics and LHCb

- $B_{(s)} \rightarrow \mu\mu$
- $B \rightarrow K^*\mu\mu$
- Search for new physics in B_s mixing or CP

- $B \rightarrow K^*\gamma$ and $B_s \rightarrow \varphi\ \gamma$
- Hadronic decays : measurement of the UT angle $\gamma\ /\varphi_3$

Search for new physics in B_s mixing or CP

- Mixing and decay governed by Schrödinger equation :

$$i\frac{\mathrm{d}}{\mathrm{d}t}\begin{pmatrix}\langle B^0|B(t)\rangle\\ \langle\overline{B}^0|B(t)\rangle\end{pmatrix}=\begin{pmatrix}M_{11}-\frac{i}{2}\Gamma_{11} & M_{12}-\frac{i}{2}\Gamma_{12}\\ M_{21}-\frac{i}{2}\Gamma_{21} & M_{22}-\frac{i}{2}\Gamma_{22}\end{pmatrix}\begin{pmatrix}\langle B^0|B(t)\rangle\\ \langle\overline{B}^0|B(t)\rangle\end{pmatrix}$$

- time evolution → mass eigenstates

$$\begin{aligned}|B_L\rangle &= p\,|B^0\rangle + q\,|\overline{B}^0\rangle\\ |B_H\rangle &= p\,|B^0\rangle - q\,|\overline{B}^0\rangle\end{aligned}$$

- 5 observables :

$$m\equiv\frac{m_H+m_L}{2}\qquad \Delta m\equiv m_H-m_L\qquad \Gamma\equiv\frac{\Gamma_H+\Gamma_L}{2}\qquad \Delta\Gamma\equiv\Gamma_L-\Gamma_H\qquad \left|\frac{q}{p}\right|$$

- 3 main parameters to measure (approximation) :

$$\Delta M\simeq 2|M_{12}|\qquad \Delta\Gamma\simeq 2|\Gamma_{12}|\cos\phi\qquad 1-\left|\frac{q}{p}\right|^2\simeq\underbrace{\left|\frac{\Gamma_{12}}{M_{12}}\right|\sin\phi}$$

mixing frequency

Measured at Tevatron

decay width difference

B_s→KK lifetime

CP violation in mixing

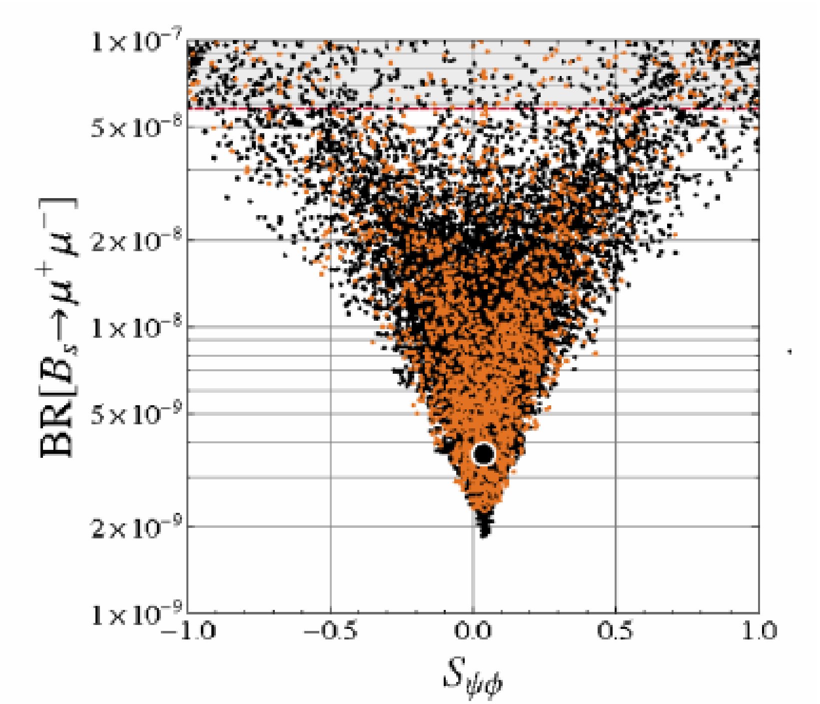
B_s→J/ψφ (CPV phase in mixing)

A^{sl}

- With NP :

$$M_{12} = M_{12}^{\rm SM} r^{\rm NP} e^{i\phi^{\rm NP}} \qquad \phi = \phi^{\rm SM} + \phi^{\rm NP}$$

- Correlation with other FCNC observables :



Altmannshofer et al, arXiv:0909.1333

Correlation between BR($B_s \to \mu\,\mu$) and CPV in $B_s \to J/\psi\ \varphi$

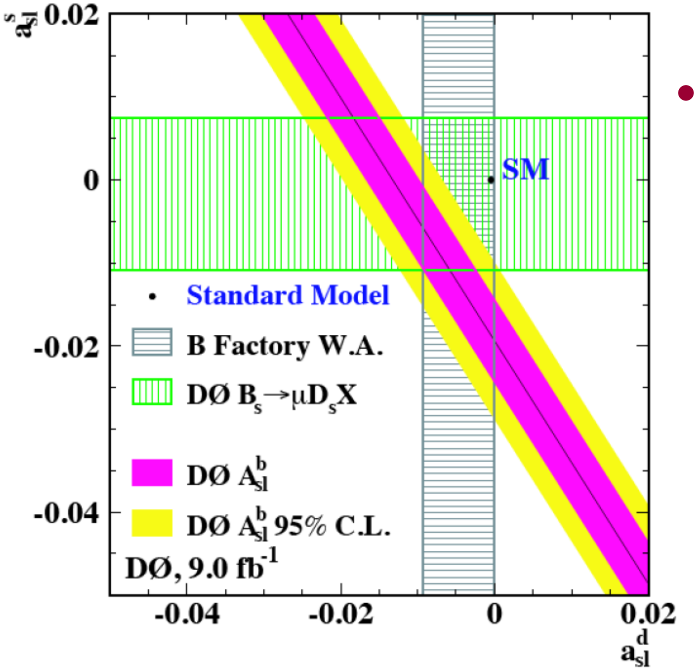
Experimental observables :

- Mixing frequency :
  - $B_s \rightarrow D_s(\rightarrow KK\ \pi)\pi$
  - flavour tagging and decay time reconstruction

$$A^{\mathrm{mix}}(t) = \frac{N^{\mathrm{unmixed}} - N^{\mathrm{mixed}}}{N^{\mathrm{unmixed}} + N^{\mathrm{mixed}}} = \cos(\Delta m_q t)$$

- CP asymmetry in dileptons :
  - CPV= 0 in decay
  - probe CPV in mixing

$$a_{fs} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$



- No result from LHCb yet :
  - more complicated that at D0 (asymmetric production)
  - Two methods :
    - -Take only Bs, control asymmetry with control channels
    - - measure the (time dependent) difference

$$\Delta A = A(B_s \rightarrow D_s(KK\pi)\mu X) - A(B_d \rightarrow D(KK\pi)\mu^- X)$$

Time dependent CPV in the B_s sector :

LHCb-CONF-2011-049
LHCb-CONF-2011-051

- mixing induced CPV due to interference in decays to common final state

$$\begin{tikzcd}
B^0 \arrow[rr, "\phi_{\mathrm{D}}"] \arrow[dr, "\phi_{\mathrm{M}}"'] & & \boldsymbol{f} \\
& \overline{B^0} \arrow[ur, "-\phi_{\mathrm{D}}"'] &
\end{tikzcd}$$

- if ***f*** is *CP eigenstate*, time dependent CP violation with pattern

$$A_{CP}(t) \equiv \frac{N(\overline{B} \to f) - N(B \to f)}{N(\overline{B} \to f) + N(B \to f)} = S \sin(\Delta m_q t)$$

flavor at production

$$\boldsymbol{S = \sin(\phi_M - 2\phi_D)}$$

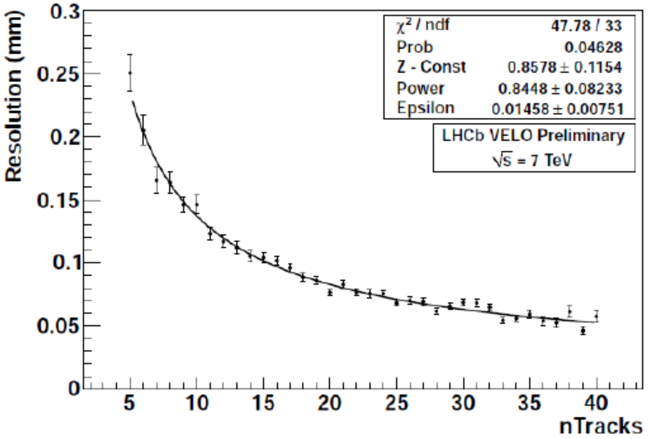
$2\beta_s$
in SM : -2.1 ±0.1°

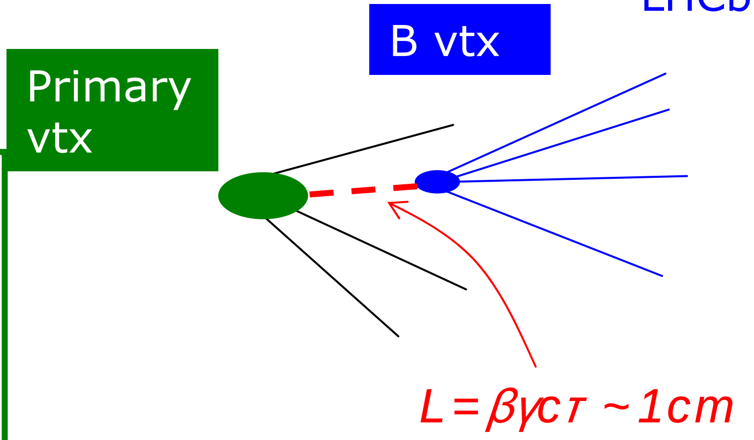
Decay time measurement and initial state flavour tagging are crucial ingredients

LHCb-CONF-2011-049

Decay time : $t = \frac{mL}{pc}$

primary vertex z-resolution vs number of tracks

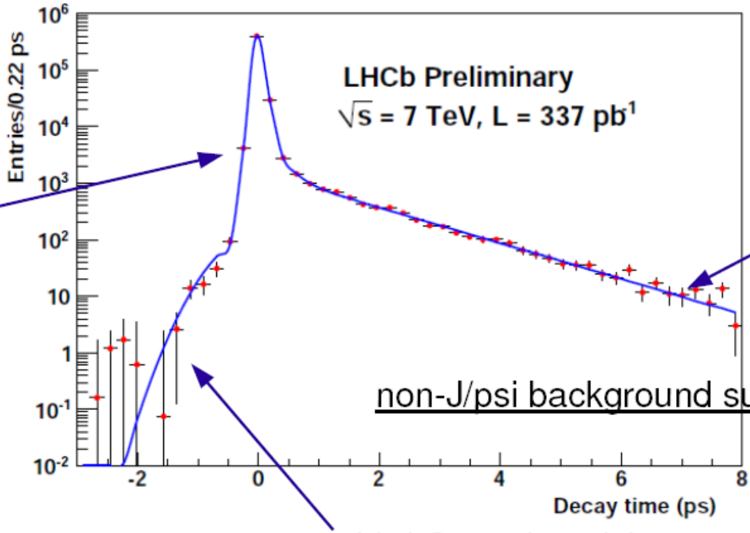




z B vertex resolution : typically 0.3 mm

Decay time resolution directly measured from data :

decay time distribution of Bs->J/psi phi candidates



signal

prompt J/ψ with 2 random tracks

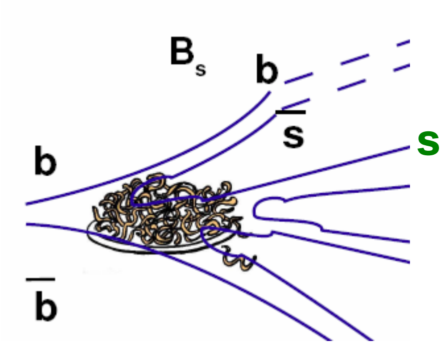
non-J/psi background subtracted

third Gaussian picks up outliers

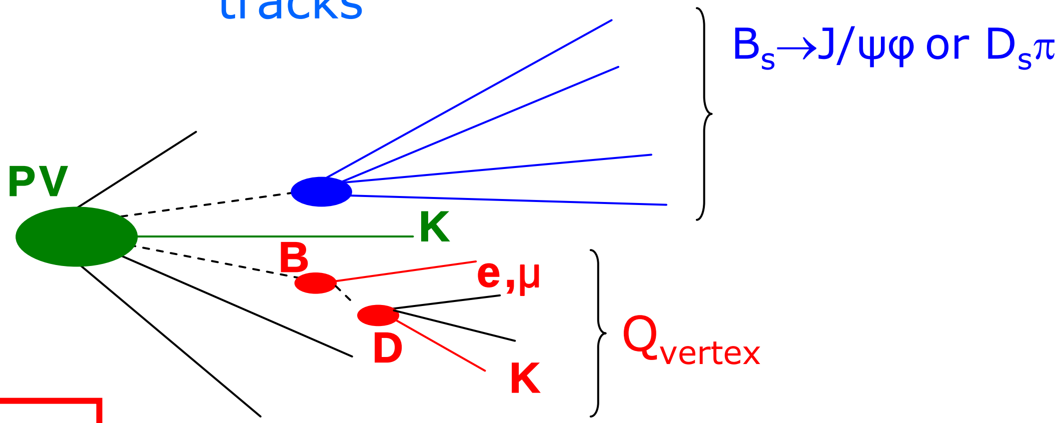
Decay time resolution ~50 fs

Initial state flavour tagging :

physics



tracks



Opposite Side Tagging in LHCb :

- Kaons
- muons, electrons
- vertex charge

Same Side Tagging in LHCb :

- identify a kaon that is close to signal B in phase space

Not yet used (winter 2012)

Performances depend on the final state :

Measured on data

$B_s \to D_s\pi$

OST: $\epsilon D^2 = (3.2 \pm 0.8)\ \%$

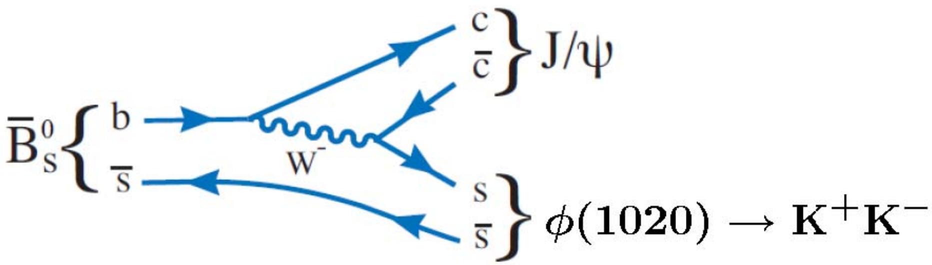
SSKT: $\epsilon D^2 = (1.3 \pm 0.4)\ \%$

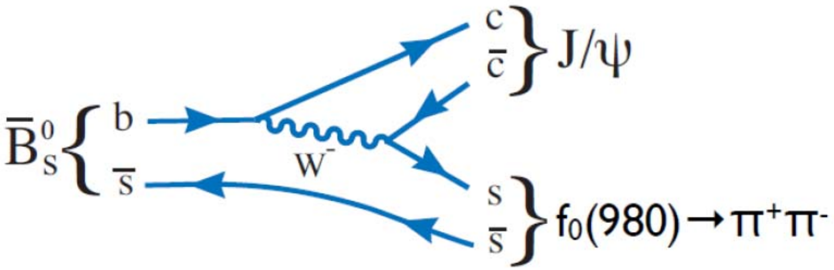
$B_u \to J/PsiK$

OST: $\epsilon D^2 = (2.1 \pm 0.4)\ \%$

$\langle D \rangle = 0.277 \pm 0.011 \pm 0.025$

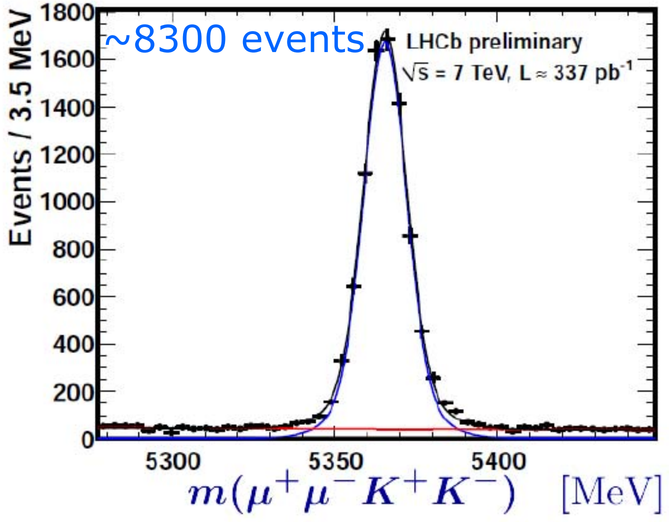
- Two main modes :

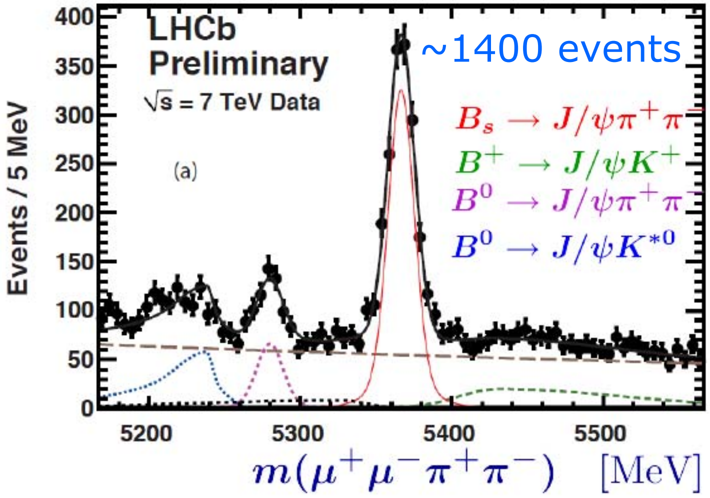




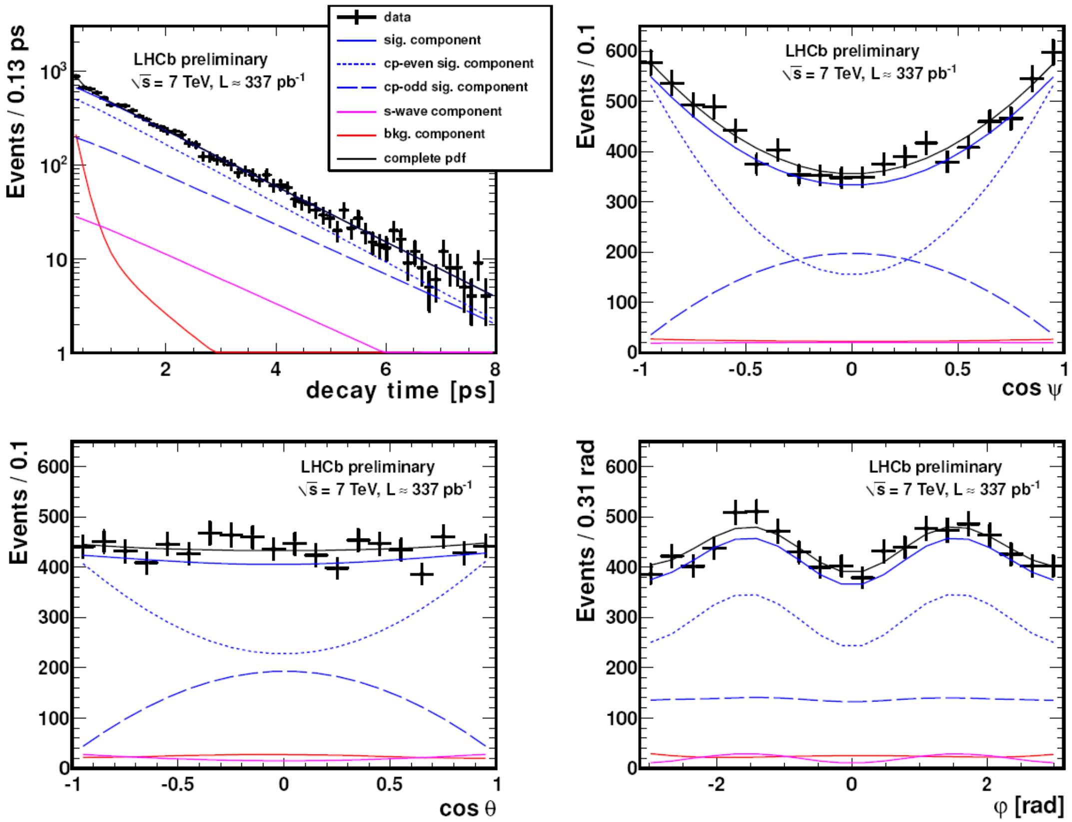
- narrow φ resonance : clean
- Vector-Vector final state (P-wave)
  - Full angular analysis (mixture of CP even and odd amplitudes)
  - Measure Γ_s $\Delta\Gamma_s$ and ϕ_s

- slightly lower BF
- Vector-Pseudo scalar final state (S-wave)
  - no angular analysis (CP odd)
  - Measure $\Delta\Gamma_s$ and ϕ_s

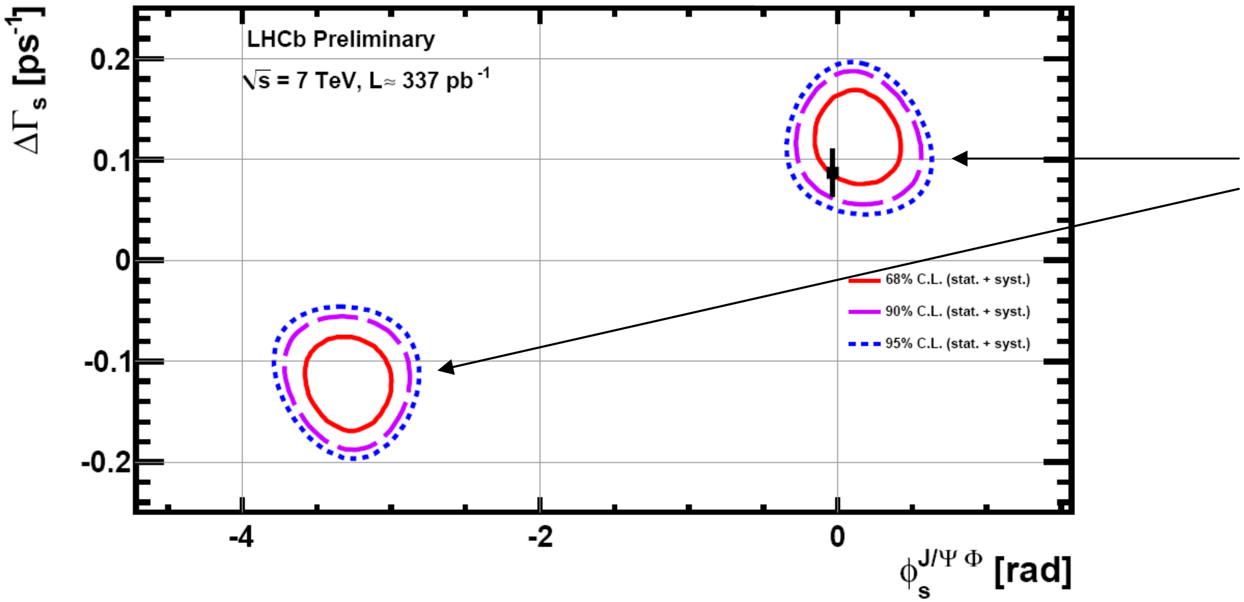

~8300 events


~1400 events

$B_s \to J/\psi\ \varphi$ fit result:

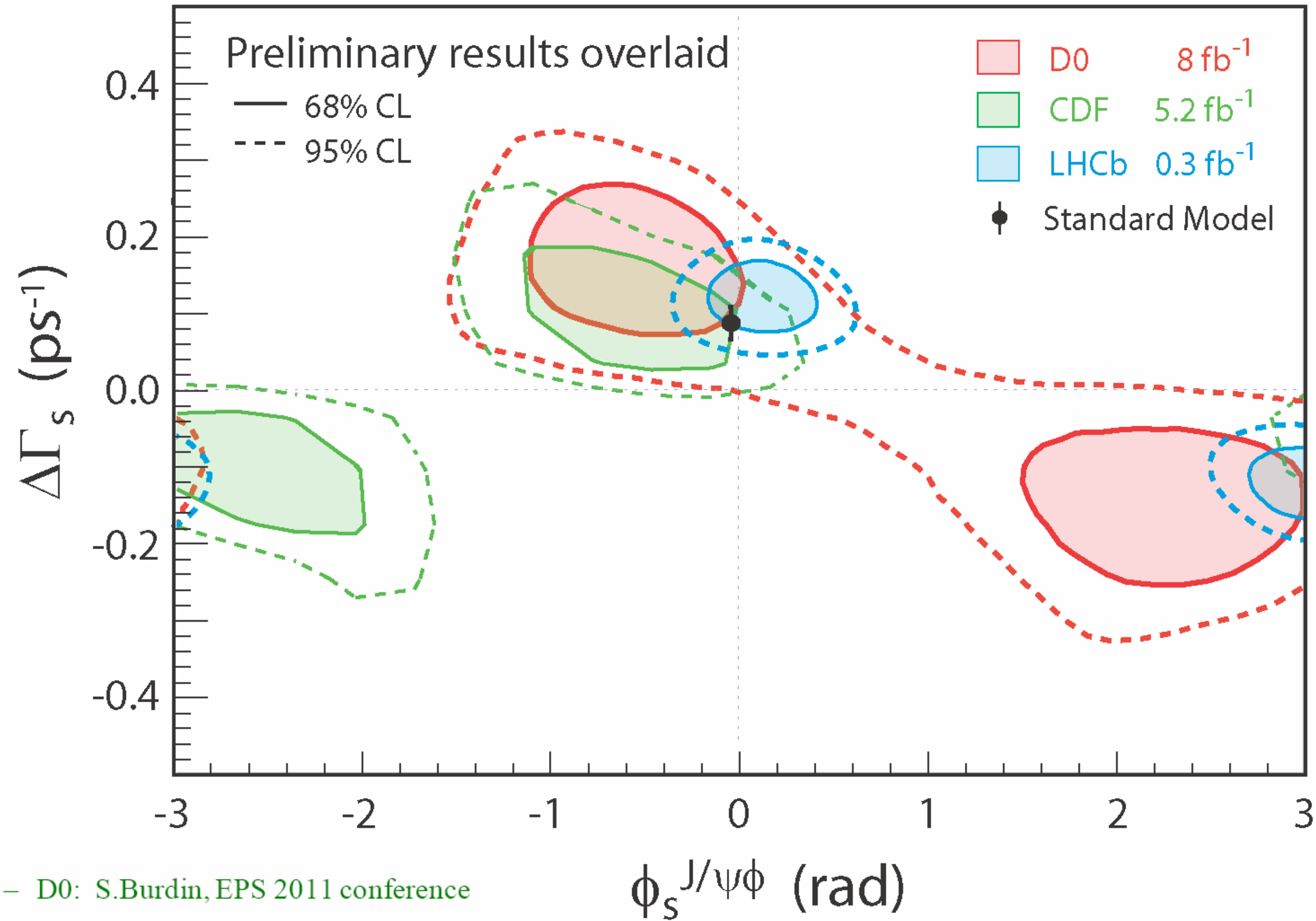


$$\boxed{\phi_s^{J/\psi\phi} = 0.13 \pm 0.18\ (\mathrm{stat}) \pm 0.07\ (\mathrm{syst})}$$



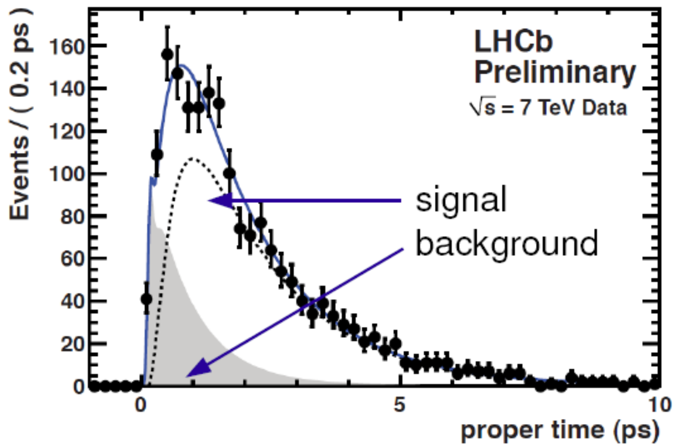
$(\phi_s,\Delta\Gamma_s) \leftrightarrow (\pi-\phi_s,-\Delta\Gamma_s)$
ambiguity

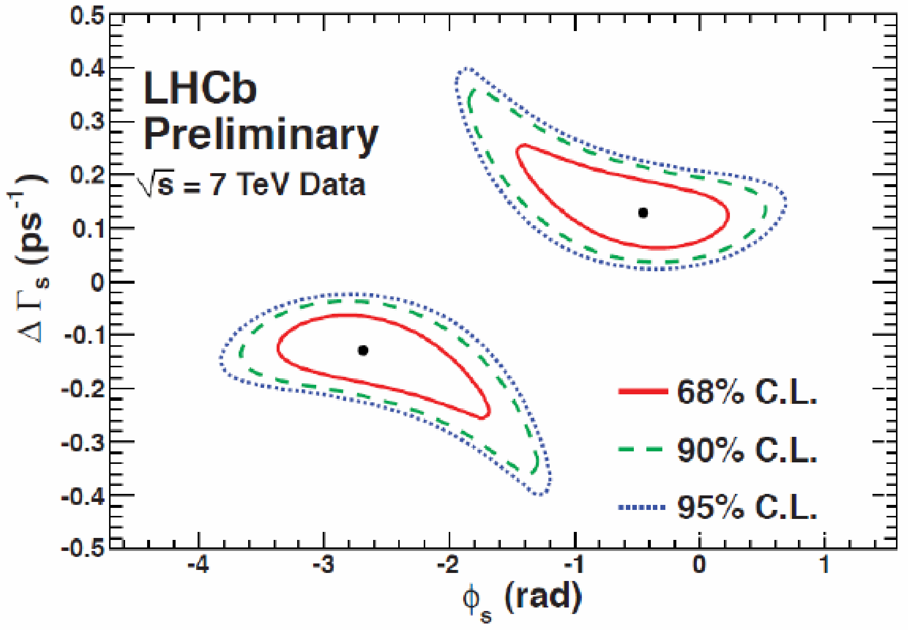
$B_s \rightarrow J/\psi\ \varphi$ result compared with Tevatron



- D0: S.Burdin, EPS 2011 conference
- CDF: Public Note 10206
- LHCb-CONF-2011-049

$B_s \to J/\psi\ f_0$ fit result



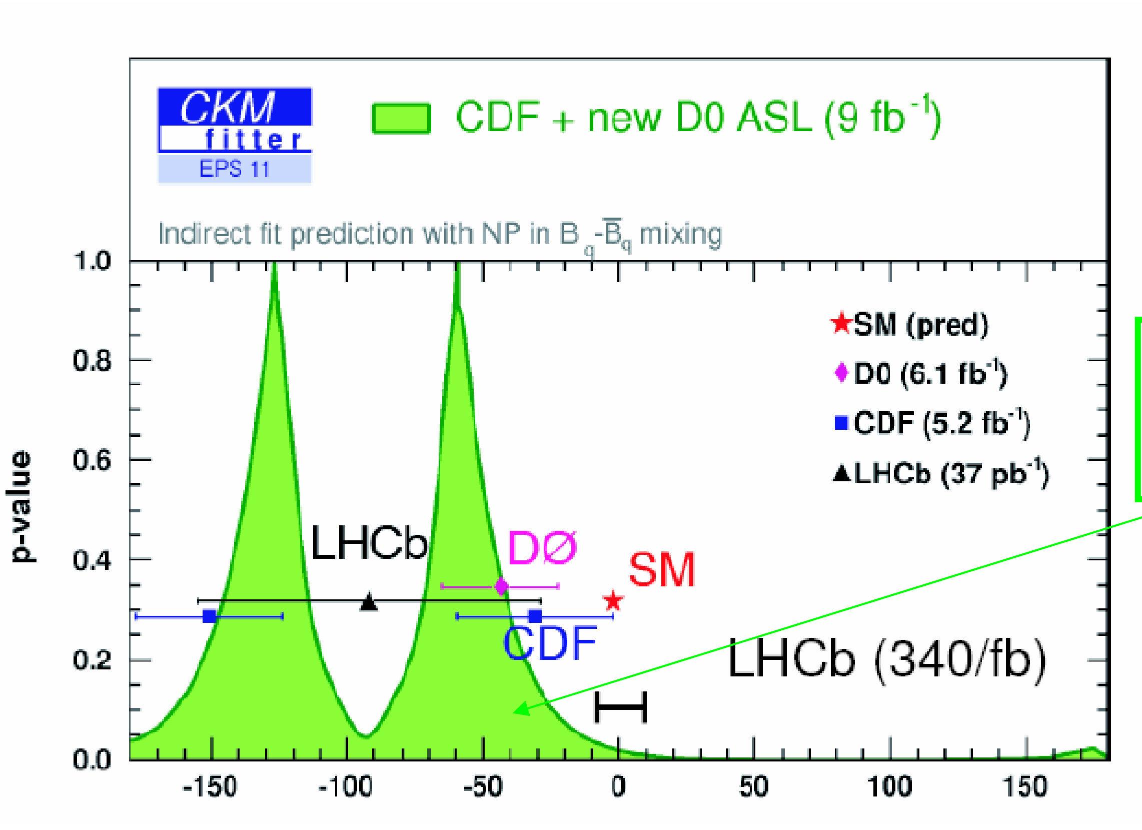


$$\boxed{\phi_s^{J/\psi f_0} = -0.44 \pm 0.44\ (\mathrm{stat}) \pm 0.02\ (\mathrm{syst})}$$

Simultaneous fit to both samples :

LHCb-CONF-2011-056

$$\phi_s = 0.03 \pm 0.16 \pm 0.07$$



Prediction from fit with NP phase, using A_{sl} but not φ_s

- With present statistics : no sign of NP
- Next :
  - we have more than 3 times the data recorded
  - add same side Kaon tagging
  - break ambiguity by fitting S-wave phase in bins of M(KK)

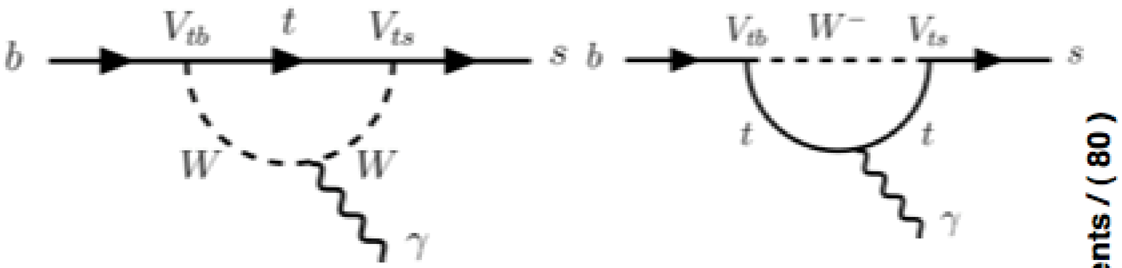
- Introduction : b physics and LHCb

- $B_{(s)} \rightarrow \mu\mu$
- $B \rightarrow K^*\mu\mu$
- Search for new physics in B_s mixing or CP

- $B \rightarrow K^*\gamma$ and $B_s \rightarrow \varphi\ \gamma$
- Hadronic decays : measurement of the UT angle $\gamma\ /\varphi_3$

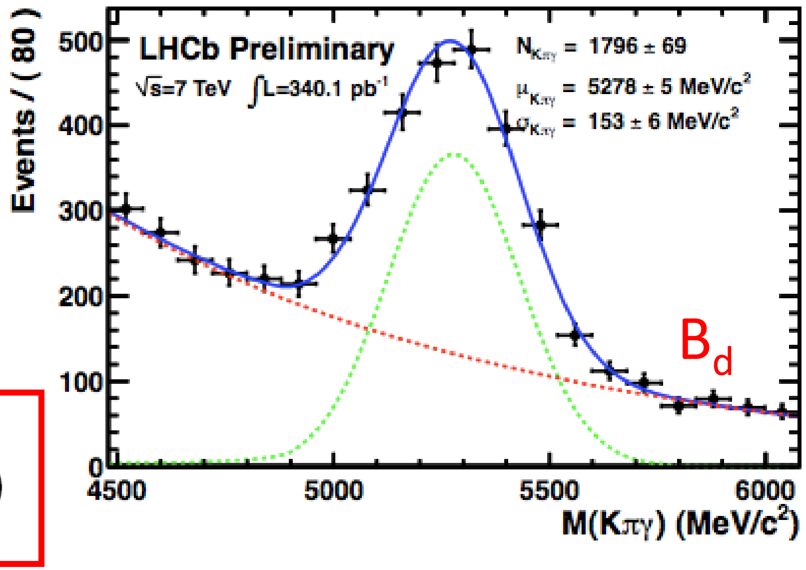
- Challenging analyses at hadron colliders :
  - background rejection
  - trigger
  - mass resolution

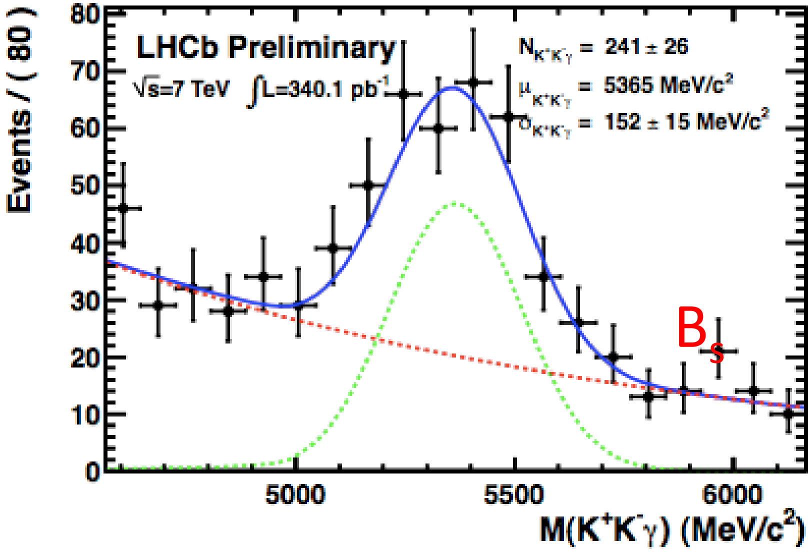
$B_s \to \varphi\,\gamma$ and $B_d \to K^*\,\gamma$



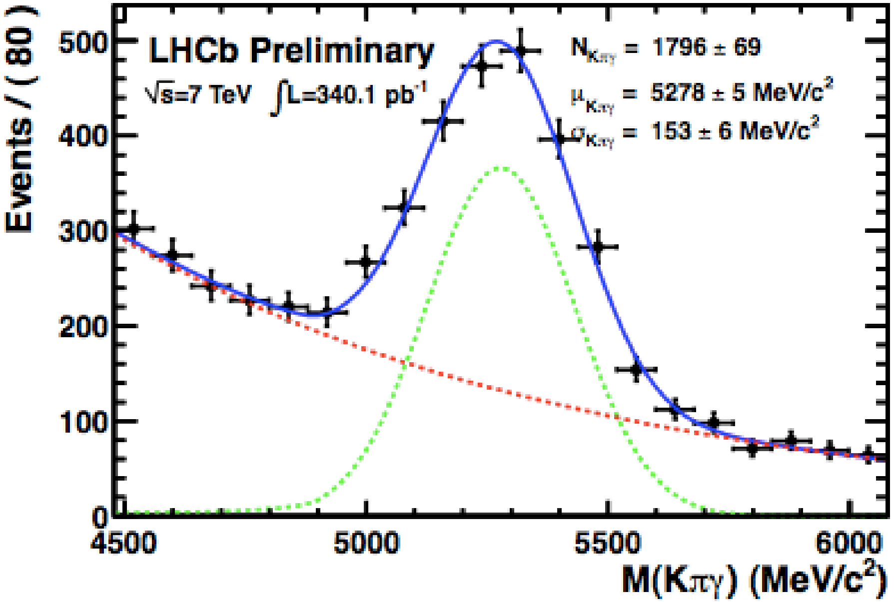
High background
Challenging for calorimeter (Highest E_T photon)

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.52 \pm 0.14(\mathrm{stat}) \pm 0.10(\mathrm{syst}) \pm 0.12(f_s/f_d)$$

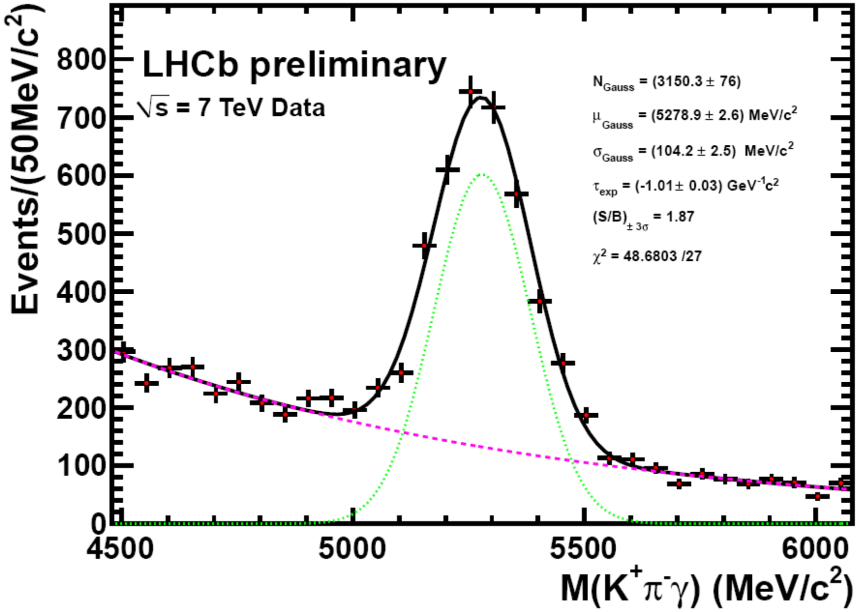




New calibration : width reduced to 100 MeV



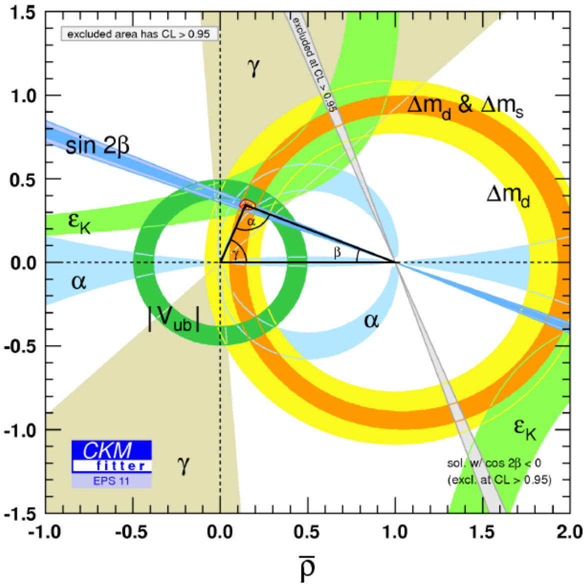
Larger data sample



Next : measure CP asymmetries

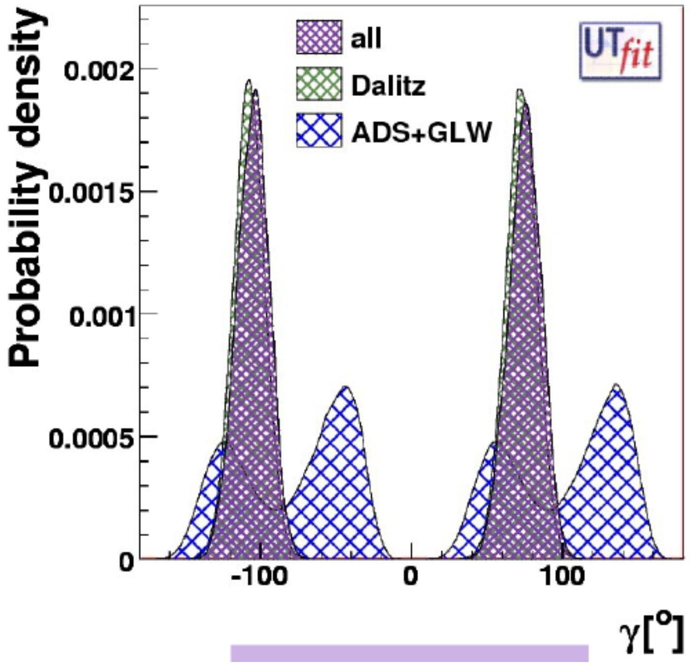
Measurement of the UT angle γ/φ_3

1. It is the most poorly measured angle :



$$\gamma/\varphi_3 = 68^{+13}_{-14}$$

$\sigma_\alpha \sim 6°$
$\sigma_\beta \sim 1°$

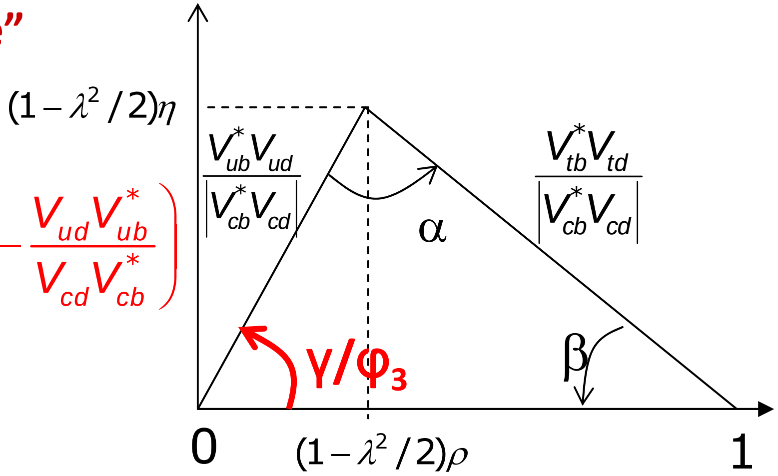


2. The direct measurement is less precise than the SM prediction (~3°)

3. "SM candle"

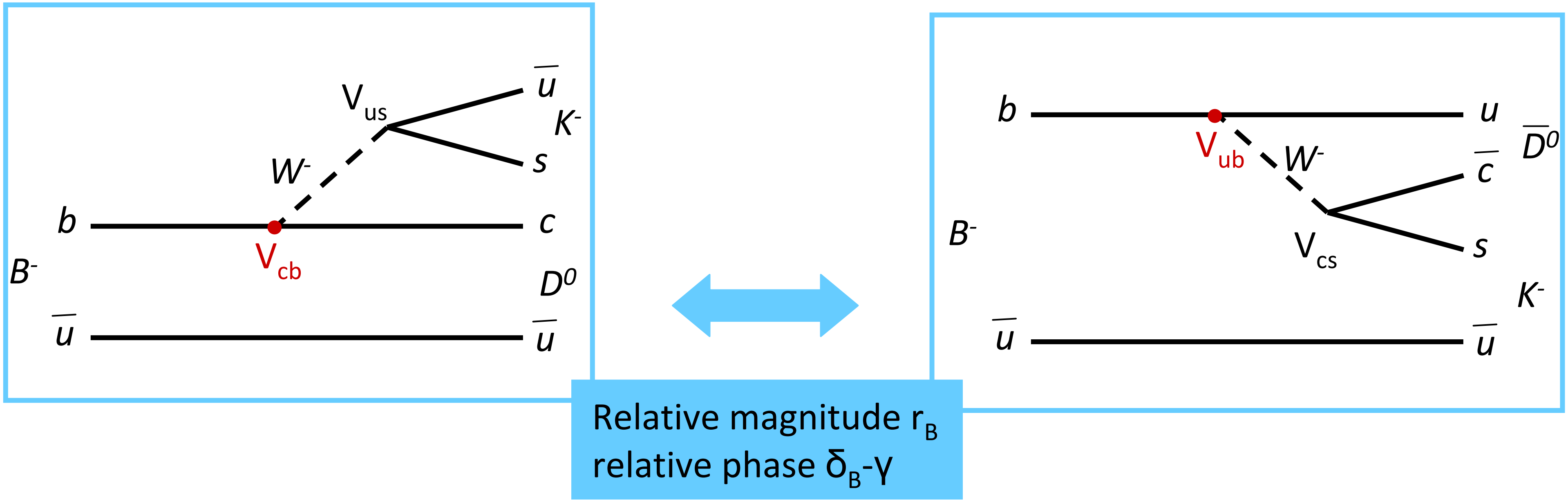
3. “SM candle”

$$\gamma / \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right)$$



Interferences between *b*→*c* and *b*→*u* transitions

NP in D^0 mixing is small



Relative magnitude r_B
relative phase δ_B-γ

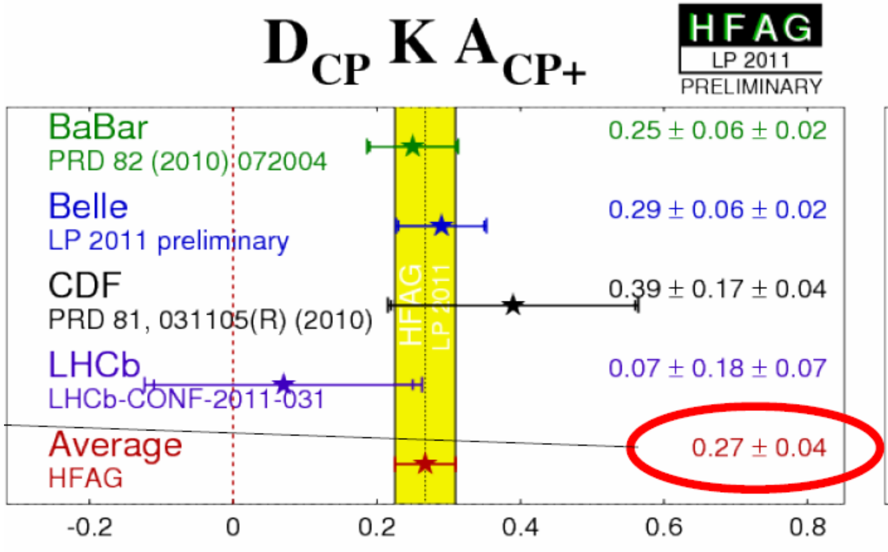
Same final state : 3 techniques :

- GLW (Gronau, London, Wyler) : use a CP mode for the D^0 decay *Physics Letters B 265(1-2), 172 – 176*

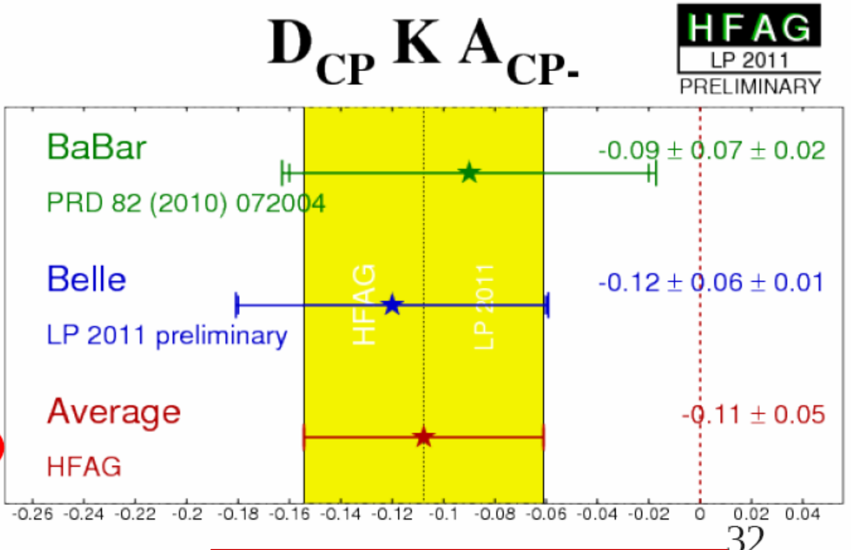
ADS (Atwood, Dunietz, Soni) : use D^0 CA($K^-\pi^+$) mode for the V_{ub} decay and D^0 DCS($K^+\pi^-$) for the V_{cb} decay *Phys. Rev. Lett. 78(17), 3257–3260*

- Dalitz GGSZ (Giri, Grossman, Soffer, Zupan) : use the $D^0 \to K_S \pi\pi$ or $K_S KK$ decays *Phys. Rev. D 68(5), 054018.*

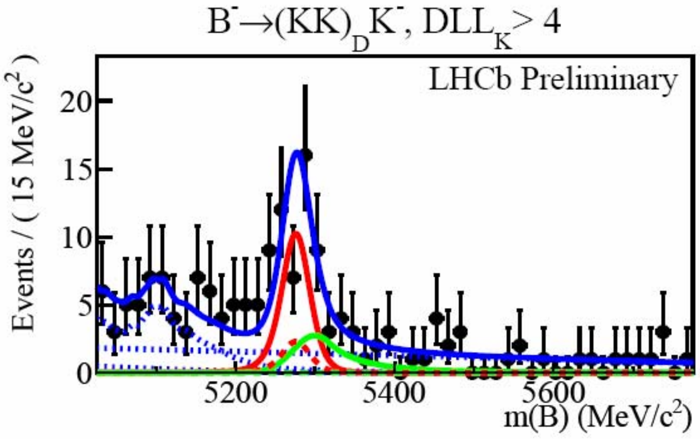
γ from B →DK, D → CP eigenstate (GLW)

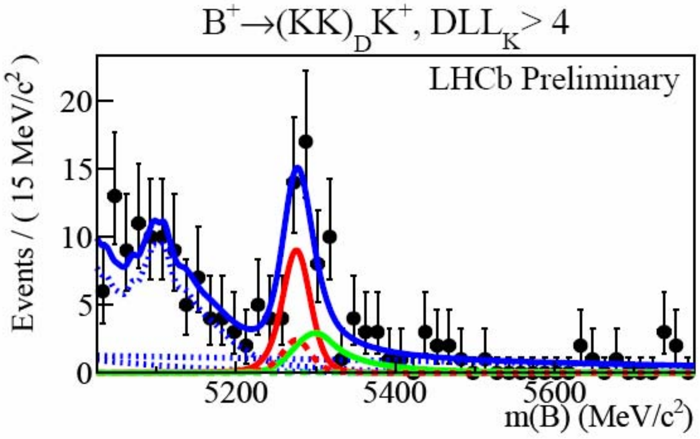


More than 6σ from 0



$$\frac{\pm 2r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2r_B \cos\delta_B \cos\gamma}$$



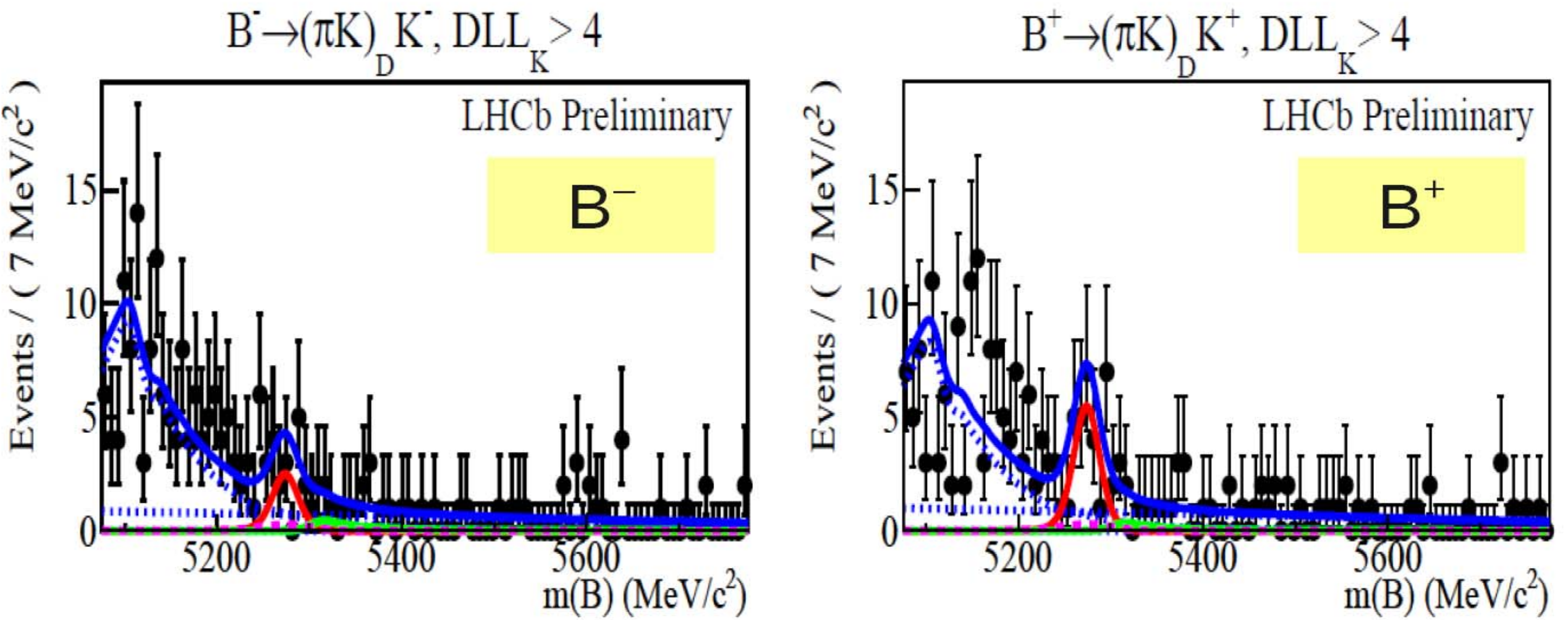


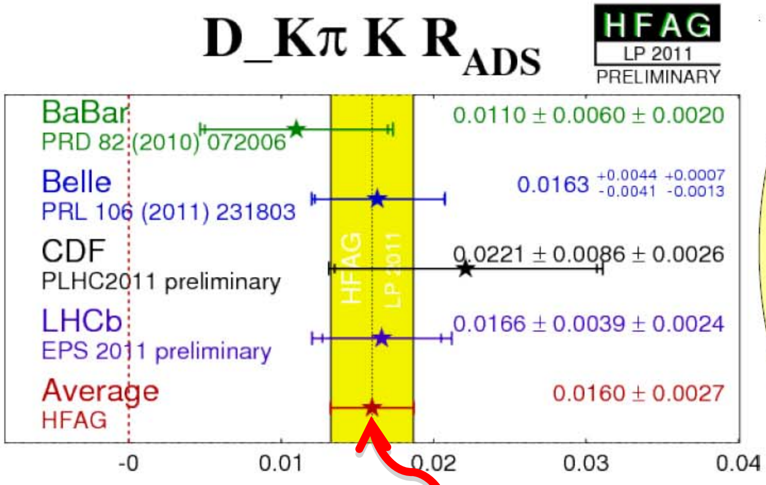
LHCb result obtained with 40 pb^{-1} only

γ from B →DK, D → Kπ (ADS)

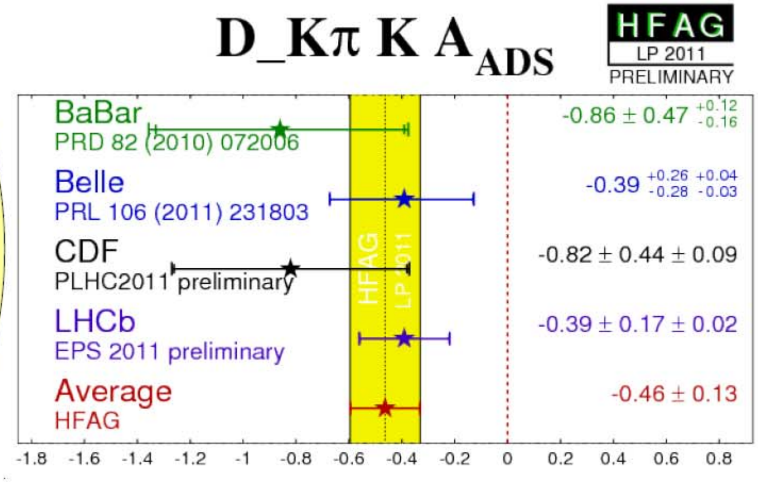
LHCb-CONF-2011-044

~300 pb^{-1}





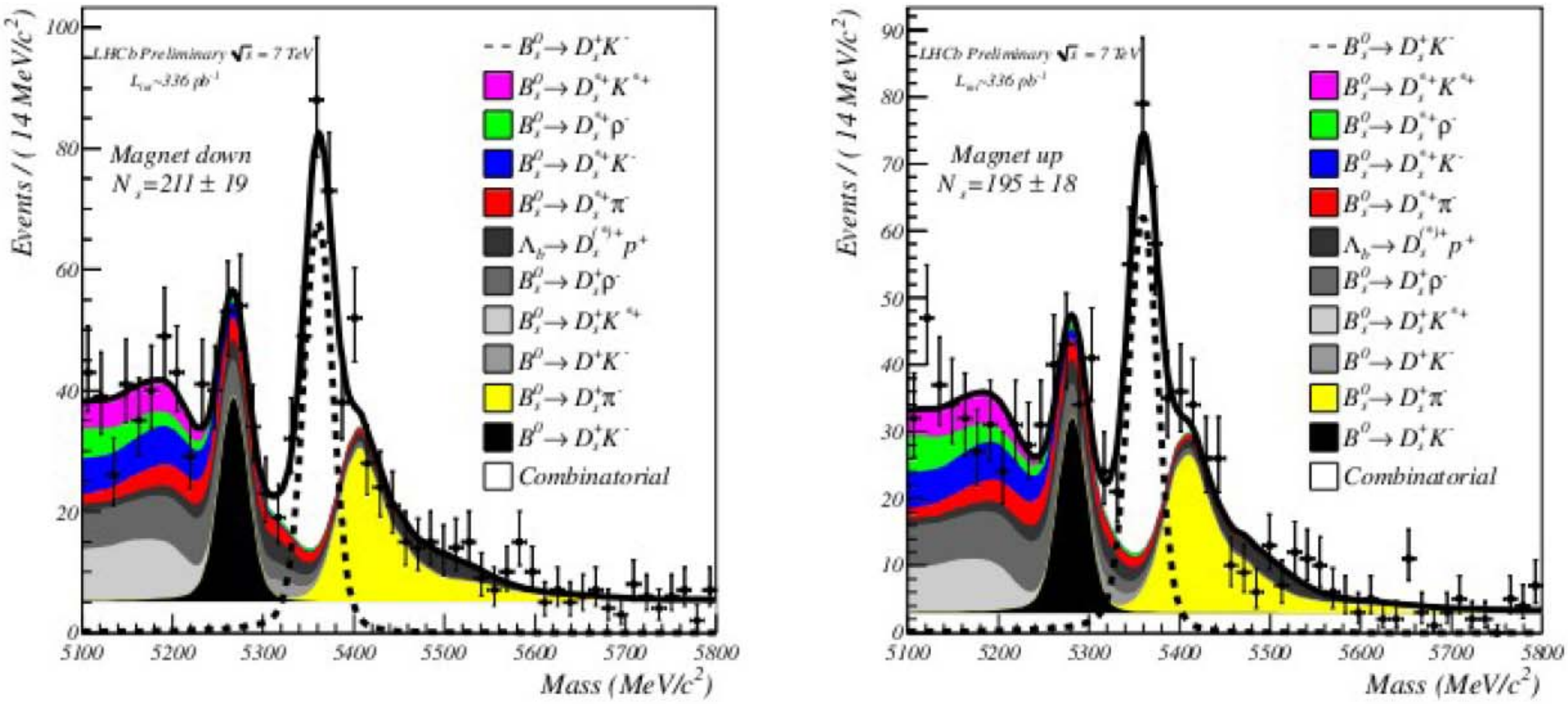
All new results in last 2 years



V_{ub} contribution clearly established

γ from $B_s \rightarrow D_sK$

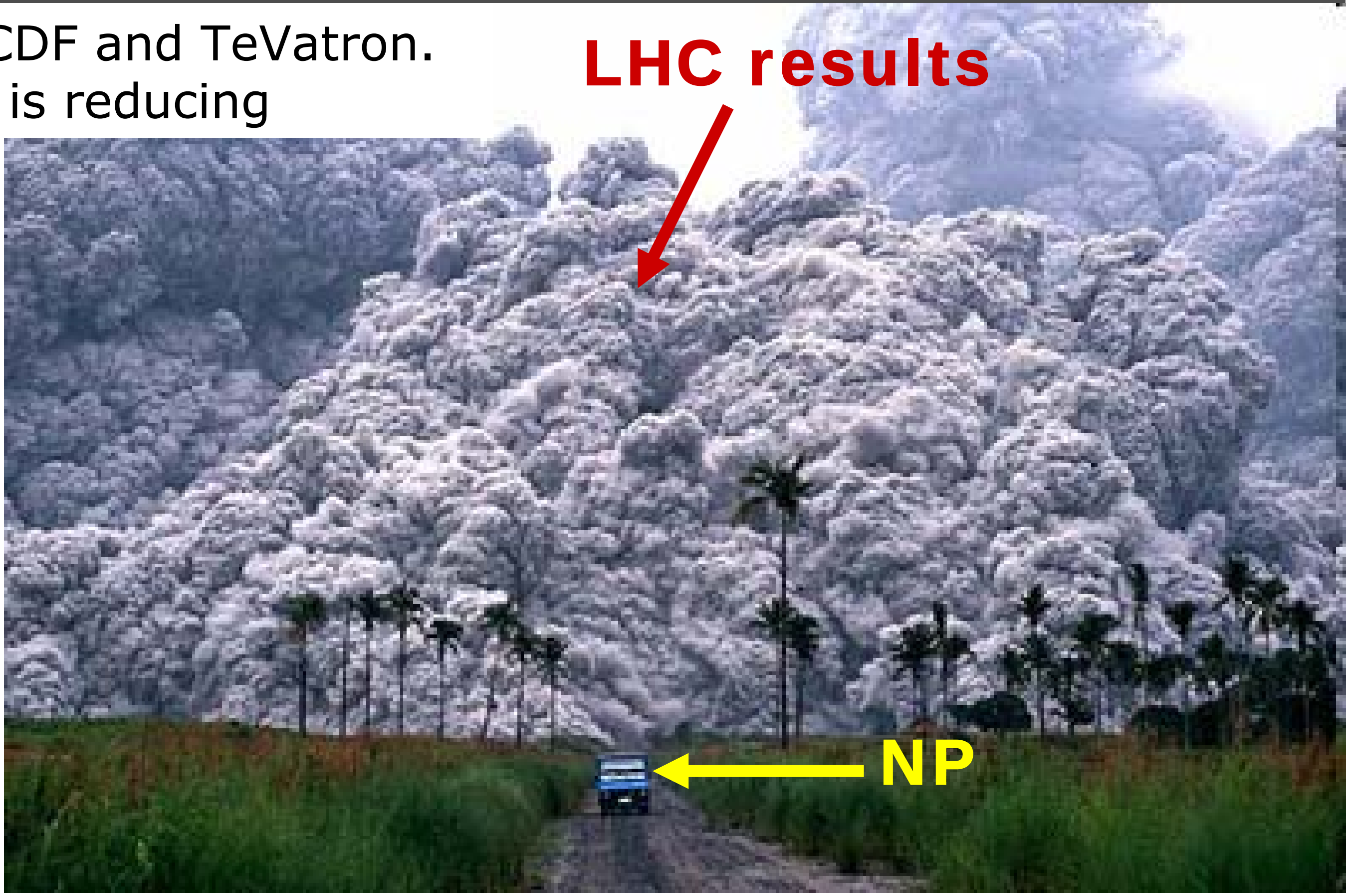
Time dependent analysis of the $B_s \rightarrow D_sK$ decays
This summer : measure the BR (split by magnet polarity)



$$B\left(B_s \rightarrow D_s^{\mp} K^{\pm}\right)=\left(1.97 \pm 0.18\,(stat)\,^{+0.19}_{-0.20}(syst)\,^{+0.11}_{-0.10}(f_s/f_d)\right) \times 10^{-4}$$

Summary

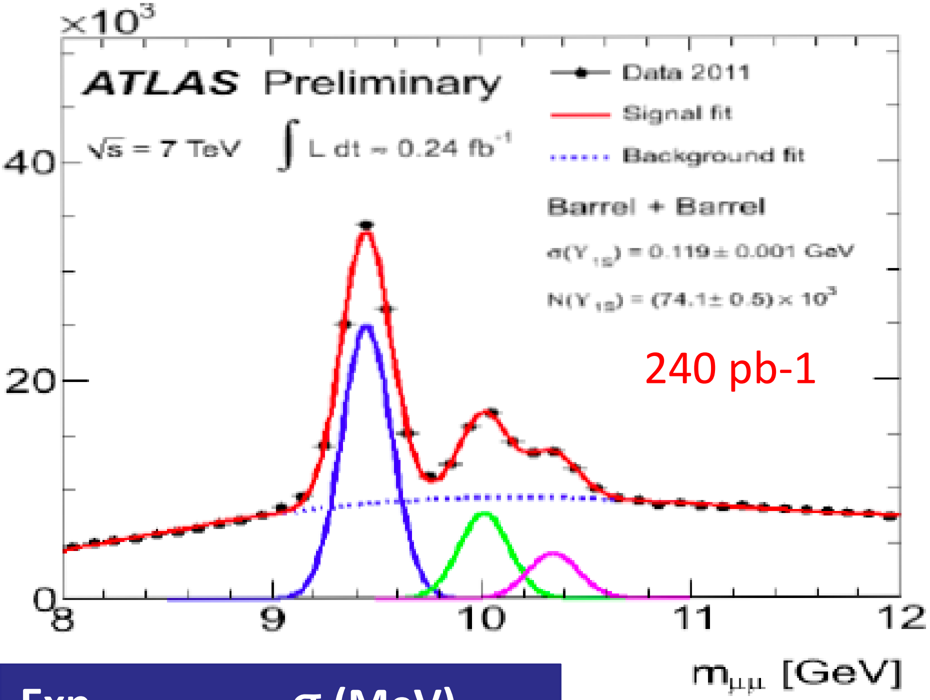
LHC(b) is taking over CDF and TeVatron.
The open space for NP is reducing



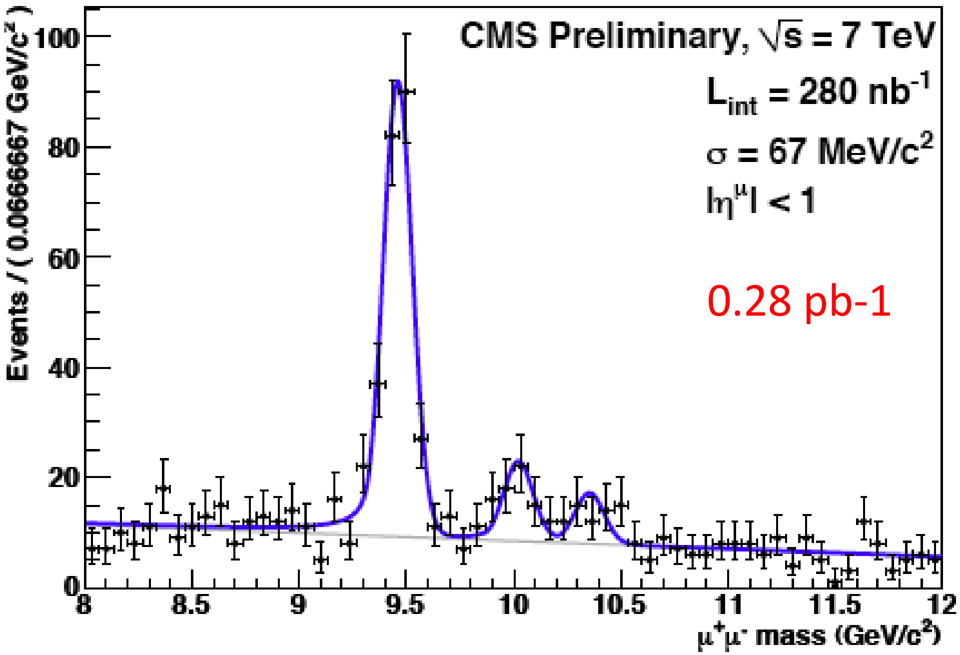
There is still room for NP, the coming year is going to be exciting

Thank you for your attention

Back up slides

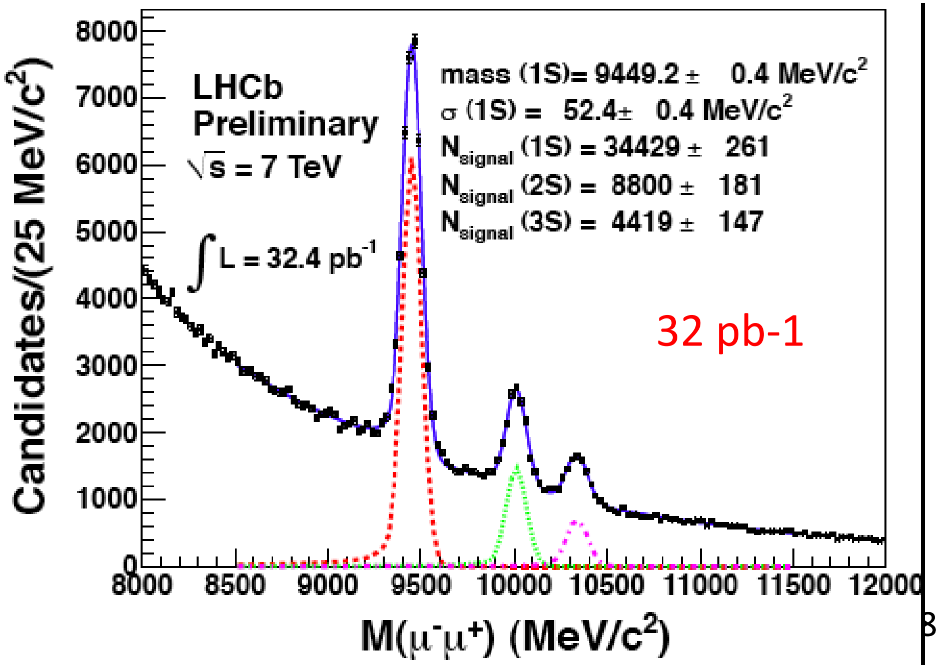


240 pb-1



0.28 pb-1

Exp	σ (MeV)
ATLAS	174
CMS	67
LHCb	52



32 pb-1

time resolution (displaced vertex)
PID
Hadronic trigger

Bs -> mumu

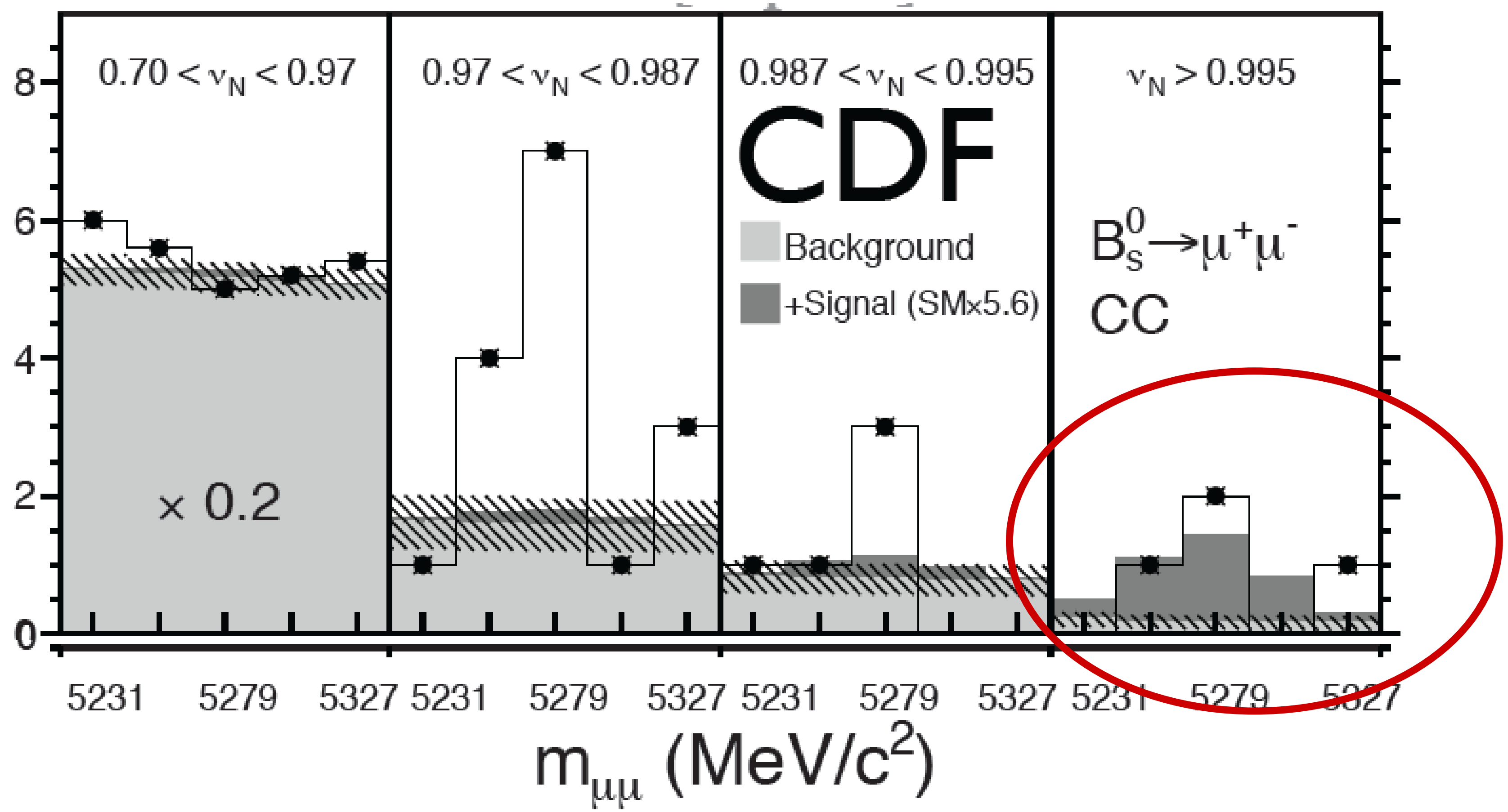
BR UL 95% CL as of Spring 2011:

CDF (3.7 fb^{-1}): $< 4.3 \times 10^{-8}$

D0 (6.1 fb^{-1}): $< 5.1 \times 10^{-8}$

LHCb (37 pb^{-1}): $< 5.6 \times 10^{-8}$

Some excitement just before EPS : CDF has reported a hint



p-value background + SM Br: 1.9%

$0.46 \times 10^{-8} < Br < 3.9 \times 10^{-8}$ at 90% CL

$Br_{CDF} (B_s \rightarrow \mu\mu) = 1.8^{+1.1}_{-0.9} \times 10^{-8}$

For Bd : $Br < 6 \times 10^{-9}$ at the 95% CL

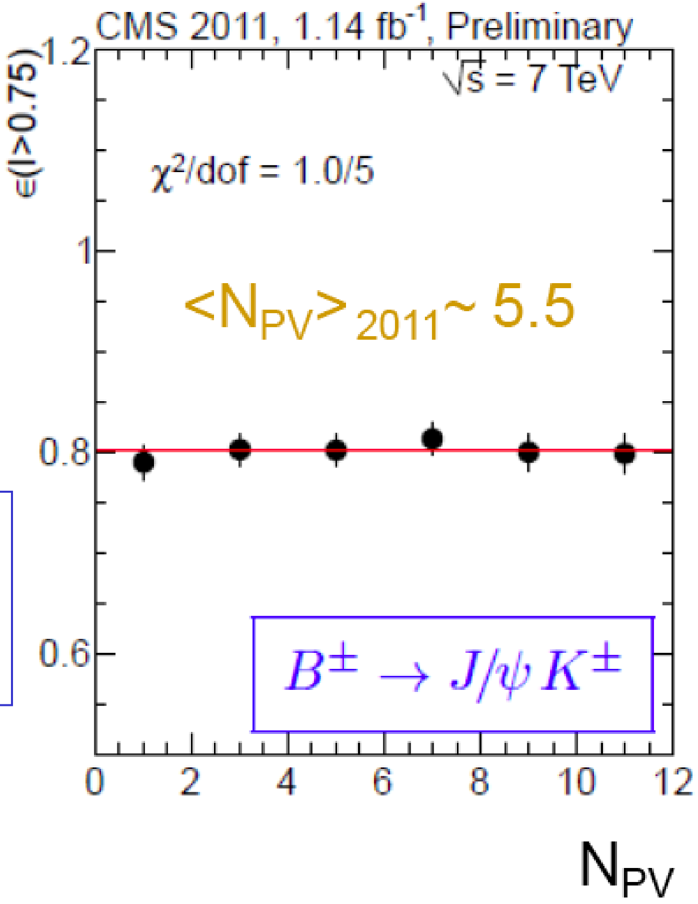
CMS

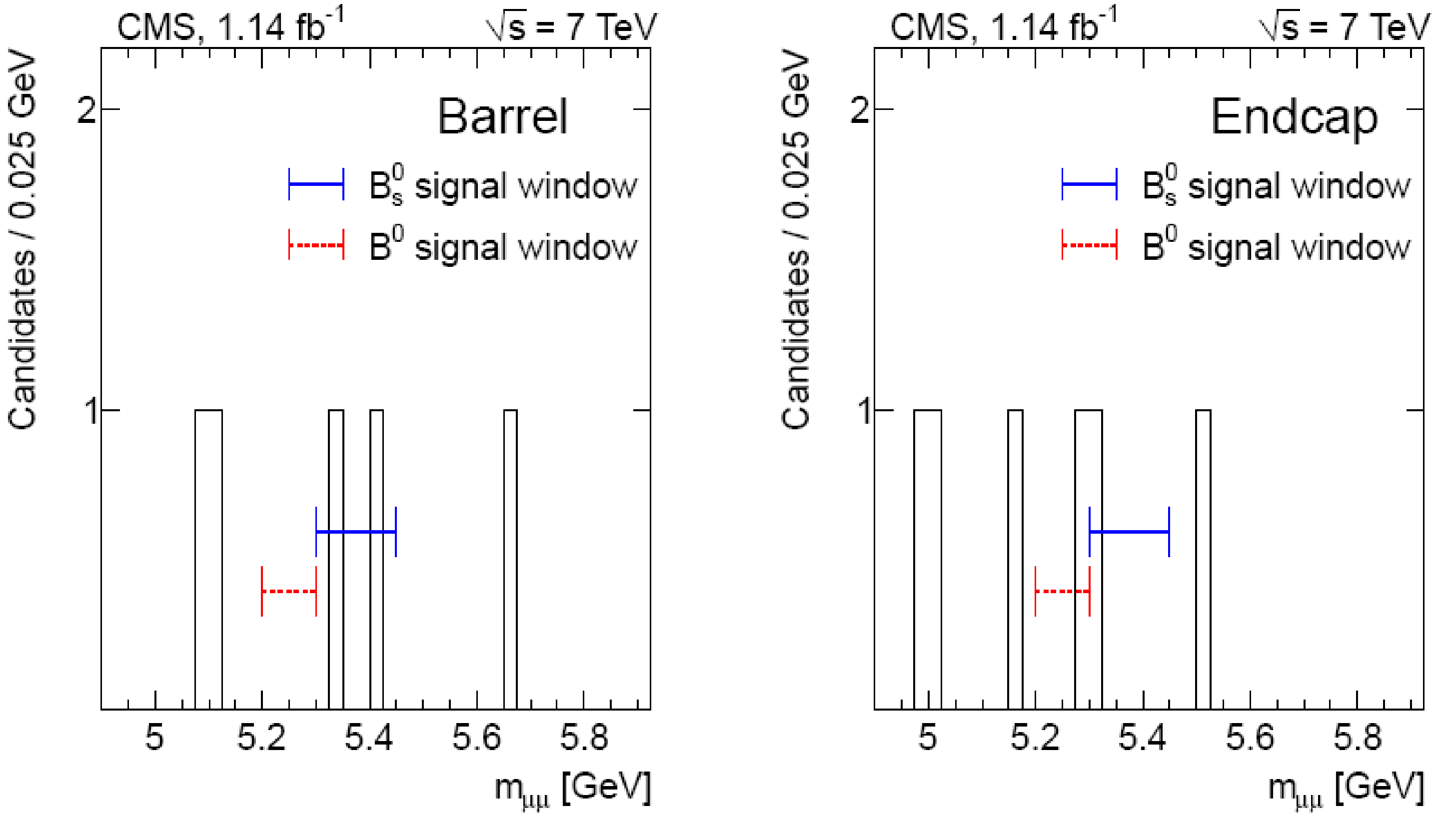
Dimuon trigger @ L1, with track information added in HLT

Cut based analysis on 1.14/fb: optimised on MC and verified on data using $B^+ \rightarrow J/\psi K^+$ & $B_s \rightarrow J/\psi \phi$ prior to unblinding

Observables well described by simulation

Efficiency and behaviour of variables potentially sensitive to pileup (e.g. Isolation,flight length) checked on data





this is B→hh

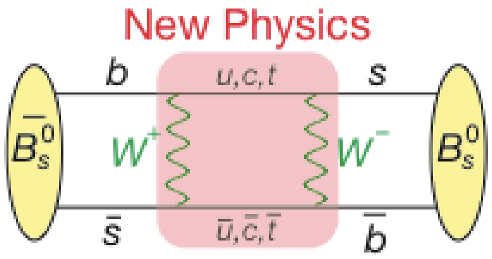
	Barrel	Endcap
$N_{\rm signal}^{\rm exp}$	0.80 ± 0.16	0.36 ± 0.07
$N_{\rm bg}^{\rm exp}$	0.60 ± 0.35	0.80 ± 0.40
$N_{\rm peak}^{\rm exp}$	0.07 ± 0.02	0.04 ± 0.01
$N_{\rm obs}$	2	1

$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.9 \times 10^{-8}$ at 95% CL.

B_s mixing and CPV : search for NP

CP Violation in B_s^0 System

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & \boxed{V_{us}} & \boxed{V_{ub}} \\ V_{cd} & \boxed{V_{cs}} & \boxed{V_{cb}} \\ V_{td} & \boxed{V_{ts}} & \boxed{V_{tb}} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



- CP violation in SM occurs in complex phases in unitary CKM matrix; new physics: plenty of new phases!!

B_s unitarity condition

$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

$$\boxed{\phi_s^{J/\psi\phi} \approx -2\beta_s = \underset{-(0.038 \pm 0.002)}{-2\beta_s^{SM}} + \phi_s^{NP}}$$

$$\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}$$

Golden mode,

Hadron Colliders

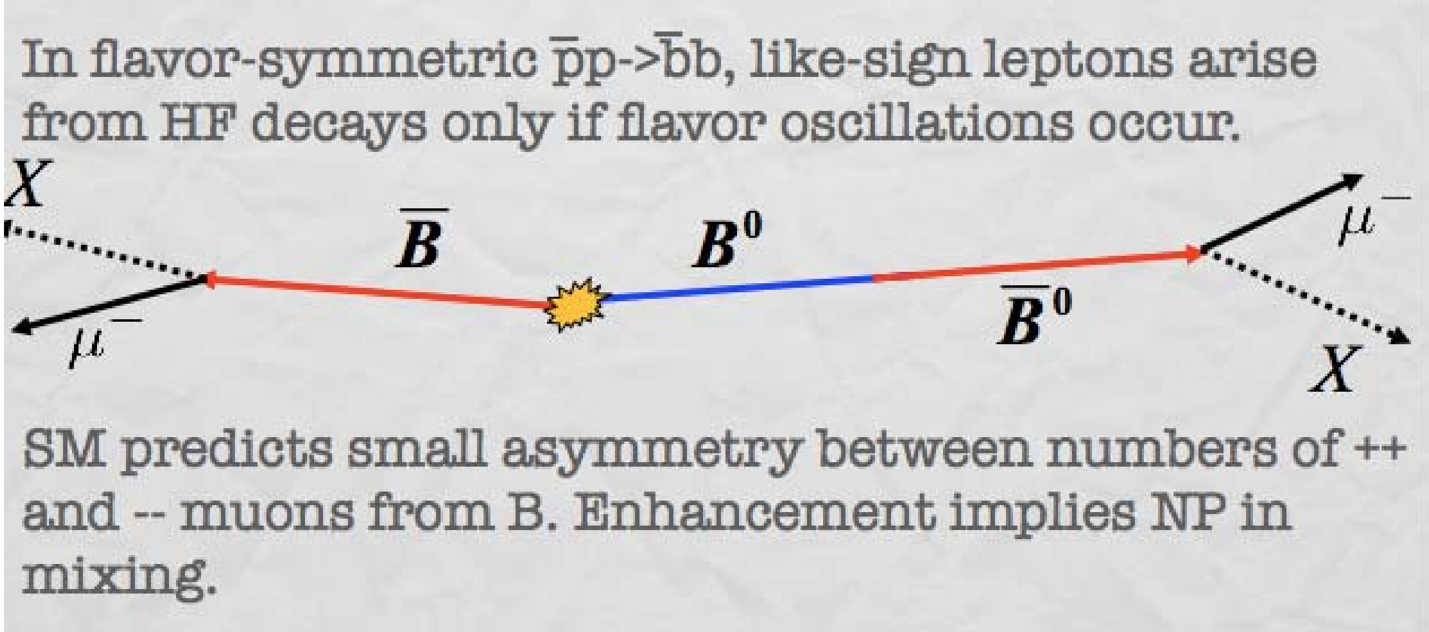
$$\begin{tikzcd} B_s^0 \arrow[rr, "decay"] \arrow[ddr, "mix"'] & & J/\psi\phi \\ & \sin 2\beta_s & \\ & \bar{B}_s^0 \arrow[uur, "decay"'] & \end{tikzcd}$$

$\phi_{\rm dec} \sim 0$

"Squashed" Triangle

CP violation through interference of diagrams with and w/o mixing

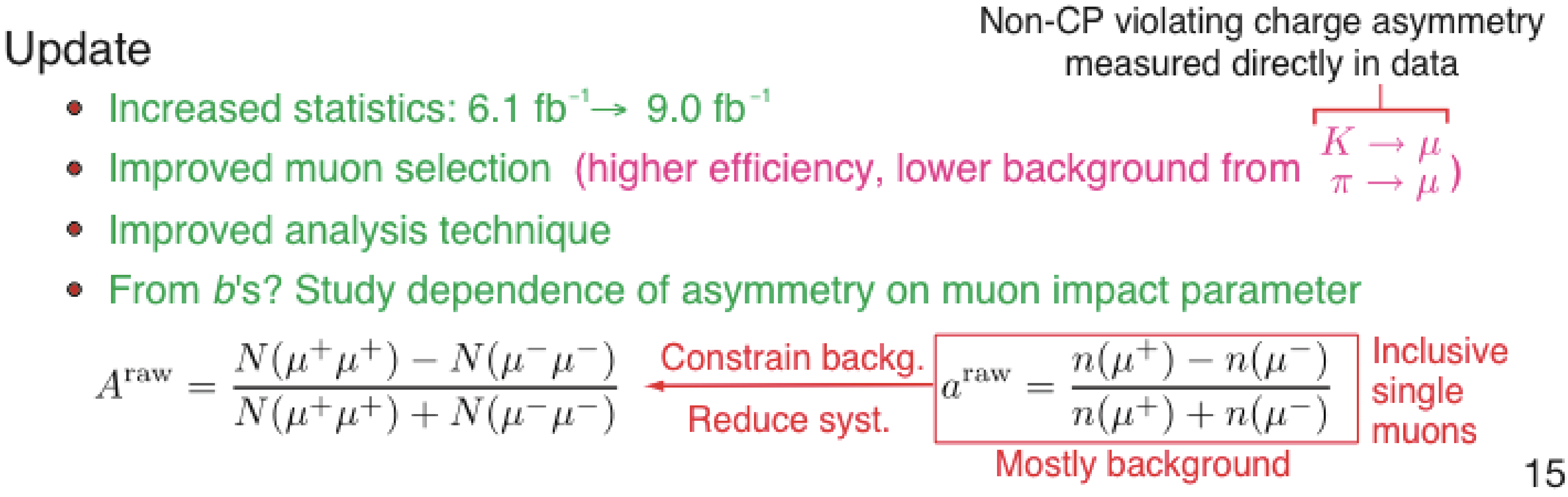
$B_{(s)}$ mixing : search for NP



In flavor-symmetric p̄p->b̄b, like-sign leptons arise from HF decays only if flavor oscillations occur.

SM predicts small asymmetry between numbers of ++ and -- muons from B. Enhancement implies NP in mixing.

- DØ: Evidence for anomalous dimuon charge asymmetry, (6 fb^{-1},PRL **105**, 081801 (2010))
  3.2σ deviation from $A^b_{sl}(SM) = (-0.023^{+0.005}_{-0.006})\%$



Non-CP violating charge asymmetry measured directly in data

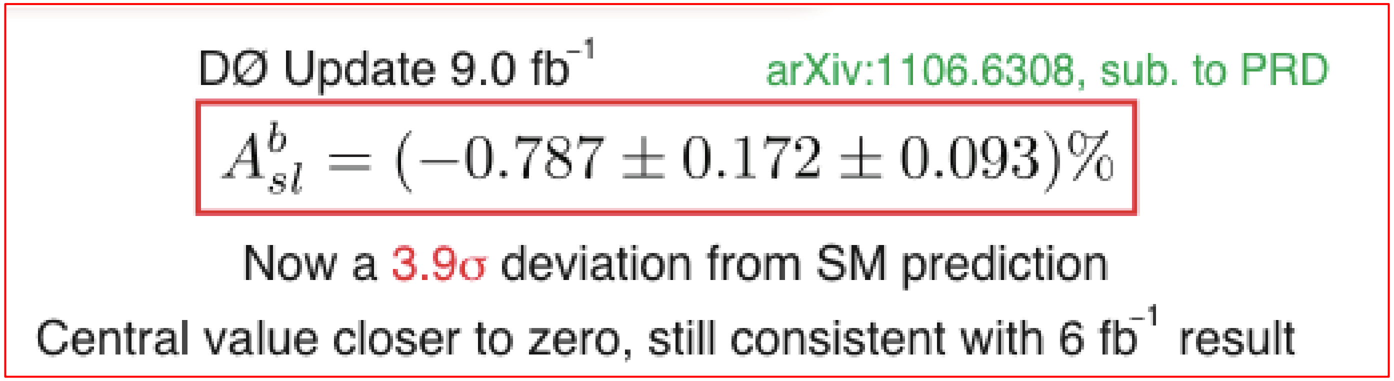
Update

- Increased statistics: 6.1 $\text{fb}^{-1} \to$ 9.0 fb^{-1}
- Improved muon selection (higher efficiency, lower background from $\left(\begin{array}{l} K\to\mu \\ \pi\to\mu \end{array}\right)$)
- Improved analysis technique
- From *b*'s? Study dependence of asymmetry on muon impact parameter

$$A^{\rm raw} = \frac{N(\mu^+\mu^+)-N(\mu^-\mu^-)}{N(\mu^+\mu^+)+N(\mu^-\mu^-)} \xleftarrow[\text{Reduce syst.}]{\text{Constrain backg.}} \boxed{a^{\rm raw} = \frac{n(\mu^+)-n(\mu^-)}{n(\mu^+)+n(\mu^-)}}$$

Inclusive single muons

Mostly background



DØ Update 9.0 fb^{-1} arXiv:1106.6308, sub. to PRD

$$\boxed{A^b_{sl} = (-0.787 \pm 0.172 \pm 0.093)\%}$$

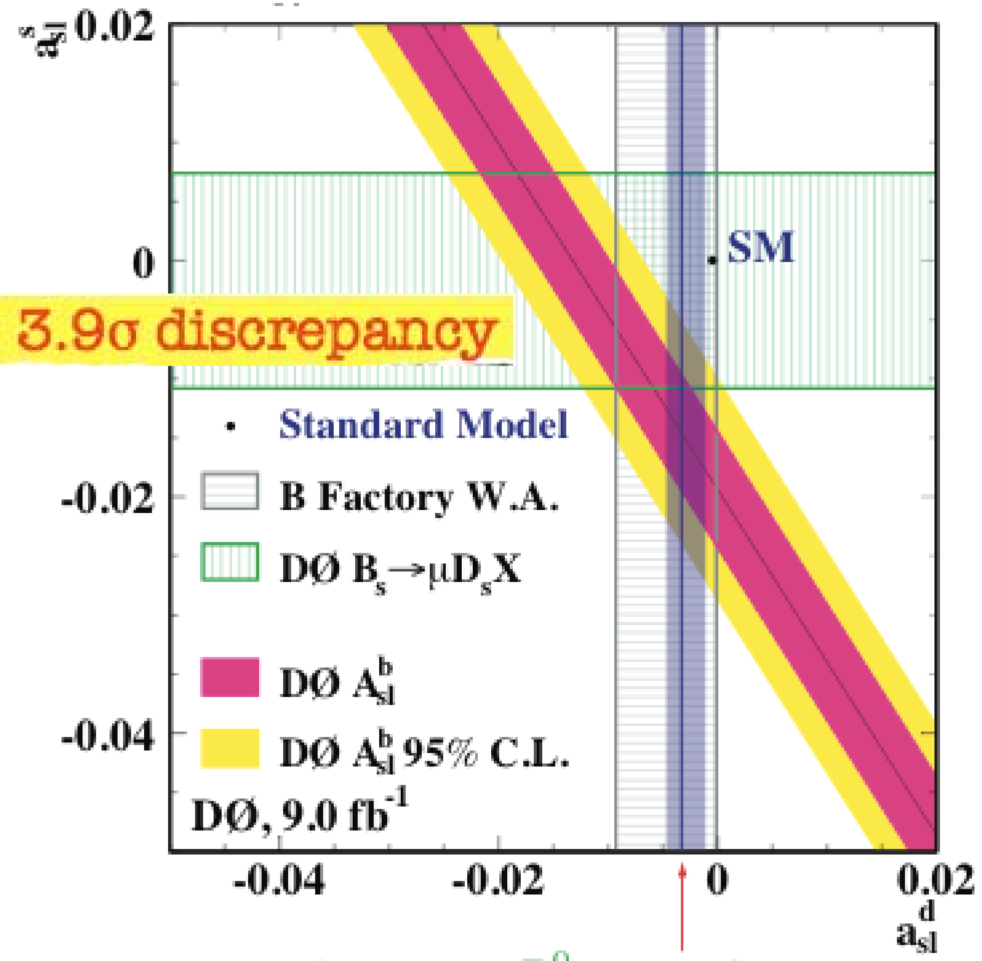
Now a 3.9σ deviation from SM prediction

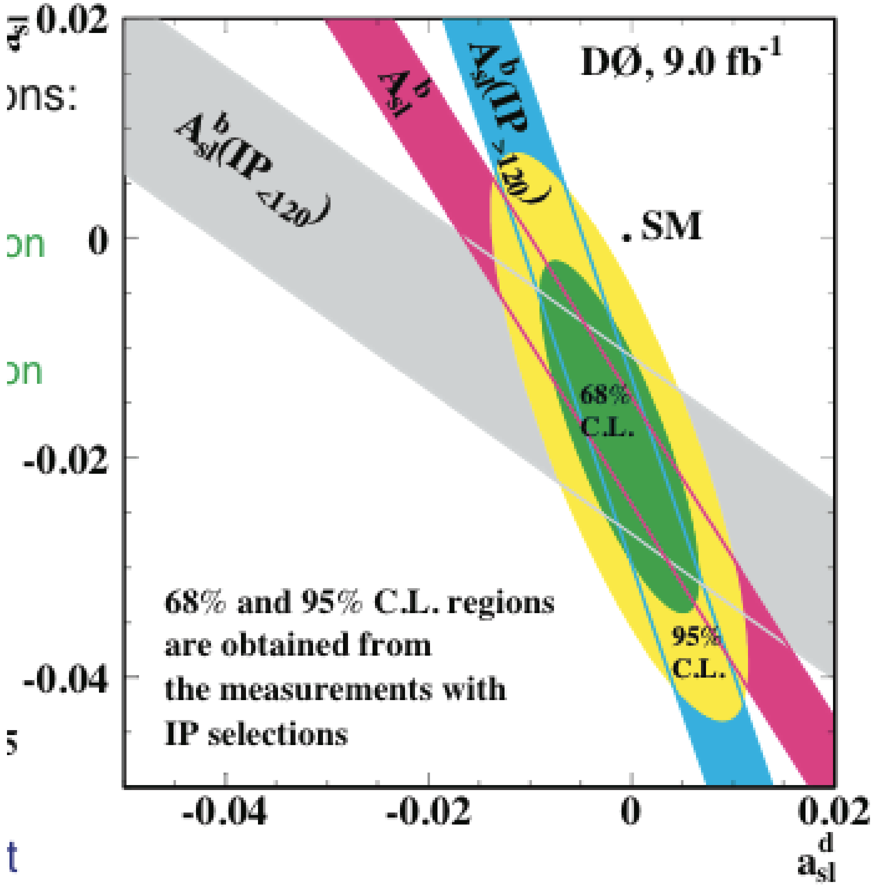
Central value closer to zero, still consistent with 6 fb^{-1} result

Asymmetry is a linear combination semileptonic charge asymmetries of B_d^0 and B_s^0

$$A_{sl}^b = C_d a_{sl}^d + C_s a_{sl}^s \; ; \qquad a_{sl}^b = \frac{\Gamma(\overline{B} \to \mu^+ X) - \Gamma(B \to \mu^- X)}{\Gamma(\overline{B} \to \mu^+ X) + \Gamma(B \to \mu^- X)}$$

C_d and C_s depend on f_d and f_s and integrated mixing probability





New physics in B_s^0 mixing? since a_{sl}^d constrained by "sin2β" in global fits:

$a_{sl}^d(\text{pred.}) = (-36^{+23}_{-11}) \times 10^{-4}$ PRD **83**, 036004 (2011)

Why γ/φ_3 at hadron colliders ?

- γ/φ_3 is not precisely measured, the result is dominated by Dalitz-GGSZ from B factories
- Sensitivity is obtained through $b \to u$ transition
- Effective BFs of the order of few 10^{-8} to few 10^{-7}

→ More statistics is needed

Challenges :

- Fully hadronic decay : trigger, background use of displaced vertices information
- PID is important : distinguish $D^0 \to K^- \pi^+$ from $D^0 \to K^+ \pi^-$

	$\sigma(b\bar{b})$	$\sigma(\text{inel})/\sigma(bb)$	$\int Ldt$	Yield ($B \to D^0_{CF} K^-$)
CDF	~ 100 µb	1000	full dataset 10fb $^{-1}$ max	1500 (5 fb^{-1})
LHCb	~290 µb	~300	0.035 fb^{-1} ; ~1fb^{-1} (end of 2011)	440 (0.035 fb^{-1})
BaBar BELLE	~1 nb	~4	425 fb^{-1} (BaBar) 700 fb^{-1} (BELLE)	~1940 (BaBar) ~3400 (BELLE)

hep-ph/0201071 (CDF)

Physics Letters B 694 (2010) 209, Eur. Phys. J. C 71 (2011) 1645 (LHCb)

SLAC-R-0504 (B factories)

GLW method

$B^{\pm}$ ⎝ $D_{\pm}$ $K^{\pm}$ at hadron collider use only D_{+} ⎝ KK or ππ

$$
\begin{aligned}
A_{\pm} &= \frac{\Gamma(B^- \to D_{\pm}K^-) - \Gamma(B^+ \to D_{\pm}K^+)}{\Gamma(B^- \to D_{\pm}K^-) + \Gamma(B^+ \to D_{\pm}K^+)} \\
&= \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma} ,
\end{aligned}
$$

$$
\begin{aligned}
R_{\pm} &= 2\,\frac{\Gamma(B^- \to D_{\pm}K^-) + \Gamma(B^+ \to D_{\pm}K^+)}{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to D^0K^+)} \\
&= 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma ,
\end{aligned}
$$

- 3 unknowns : r_B , δ_B and γ /φ_3
- 3 independent quantities ($R_+A_+ = - R_-A_-$)
- 2 measurements at hadron colliders

➔ should be combined with other methods

Could be also done using B^0 ⎝ $D_{\pm}$ K^{*0}
Different r_B , δ_B (r_B ~3 times larger)

	BR	r_B
$B^+ \to D^0K^+$	$(3.7 \pm 0.3)\ 10^{-4}$	0.1
$B^0 \to D^0K^{*0}$	$(4.2 \pm 0.6)\ 10^{-5}$	~0.3

ADS method

$B^\pm$ → D $K^\pm$ at hadron collider use only D_{DCS} → $K^+ \pi^-$ and D_{CF} → $K^- \pi^+$

$$A_{ADS} = \frac{\Gamma\left(B^- \to D_{DCS}K^-\right) - \Gamma\left(B^+ \to \overline{D}_{DCS}K^+\right)}{\Gamma\left(B^- \to D_{DCS}K^-\right) + \Gamma\left(B^+ \to \overline{D}_{DCS}K^+\right)} = \frac{2r_B r_{K\pi}\sin\left(\delta_B + \delta_{K\pi}\right)\sin\gamma}{r_B^2 + r_{K\pi}^2 + 2r_B r_{K\pi}\cos\left(\delta_B + \delta_{K\pi}\right)\cos\gamma}$$

$$R_{ADS} = \frac{\Gamma\left(B^- \to D_{DCS}K^-\right) + \Gamma\left(B^+ \to \overline{D}_{DCS}K^+\right)}{\Gamma\left(B^- \to D_{CF}K^-\right) + \Gamma\left(B^+ \to \overline{D}_{CF}K^+\right)} = r_B^2 + r_{K\pi}^2 + 2r_B r_{K\pi}\cos\left(\delta_B + \delta_{K\pi}\right)\cos\gamma$$

•3 unknowns (same as GLW) : r_B , δ_B and γ /φ_3

• $r_{K\pi}$, $\delta_{K\pi}$ known from elsewhere (CLEO-c)

Phys Rev D80, 031105(R) (2009)

$$r_{K\pi} = \left|\frac{A\left(D^0 \to K^+\pi^-\right)}{A\left(D^0 \to K^-\pi^+\right)}\right| = 0.0613 \pm 0.0010$$

•2 independent quantities

→ should be combined with other methods to extract γ

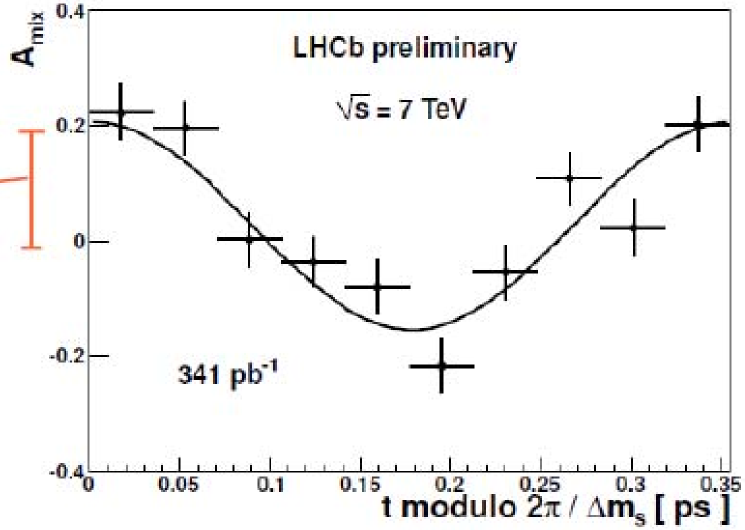
Could be also done using B^0 → D K^{*0}
Different r_B , δ_B (r_B ~3 times larger)

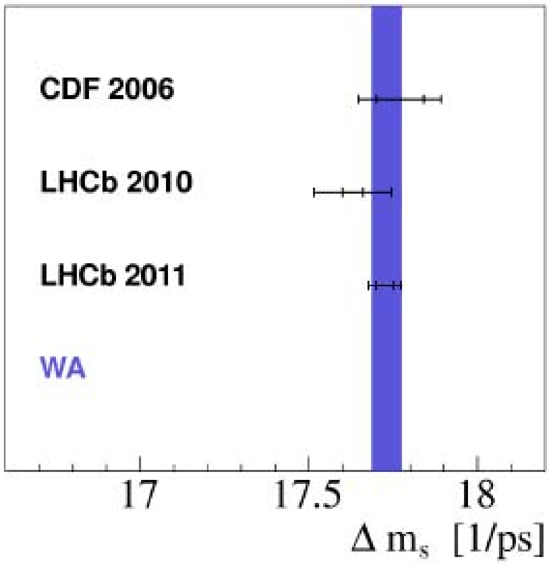
Could also be done with other D decay modes (quasi 2-body)

Δm_s in LHCb

one way to visualize result:
plot mixing asymmetry versus
(decay time) %($2\pi\Delta m_s$)

$$A^{\rm mix} = D_{\rm tag}\, D_{\rm reso} \cos(\Delta m t)$$





LHCb measurement dominates WA

$$\Delta m_s^{\rm WA} = 17.731 \pm 0.045 \ {\rm ps}^{-1}$$

error much smaller than theory error

$$\Delta m_s^{\rm SM} = 16.8^{+2.6}_{-1.5} \ \ {\rm ps}^{-1}$$

[PRD.83, 036004 (2011)]

but some theory errors in ratios cancel:

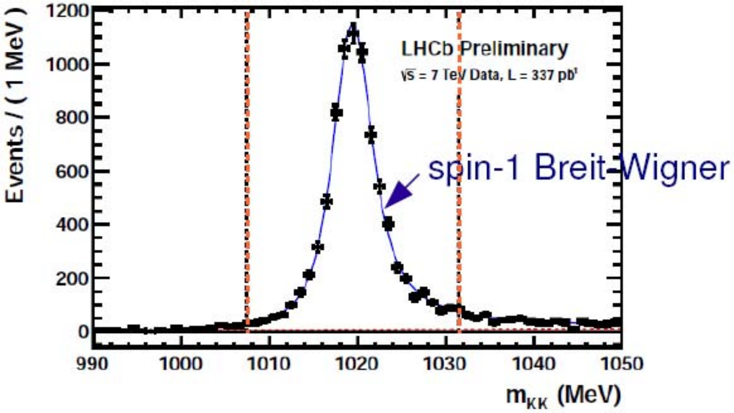
$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2090 \pm 0.0009 \pm 0.0046$$

exper. lattice

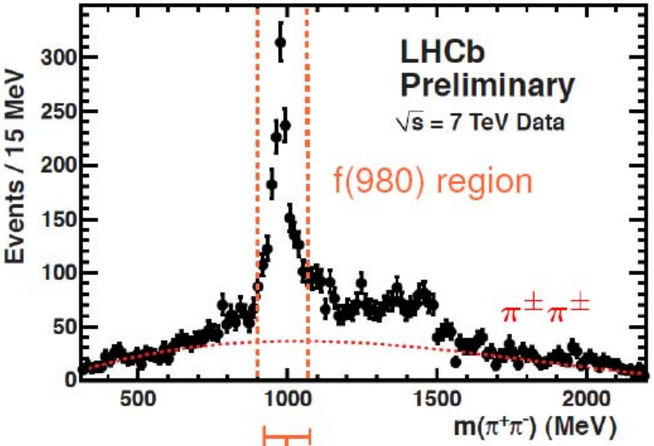
(average by Van Kooten, LP'11)

KK P wave and PiPi S-wave

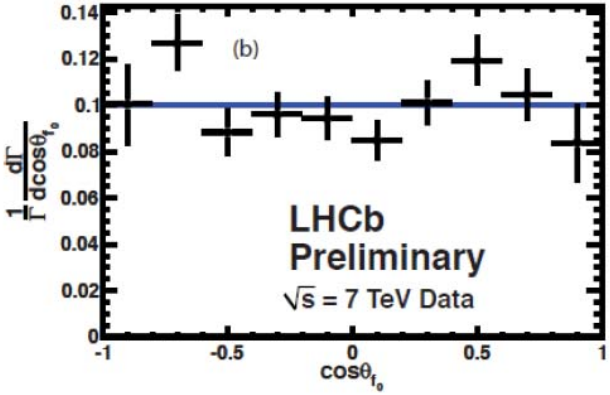
m(KK) for Bs->J/psiphi candidates, background subtracted



m($\pi\pi$) for Bs->J/$\psi\pi\pi$ candidates, not *background subtracted*



decay angle distribution

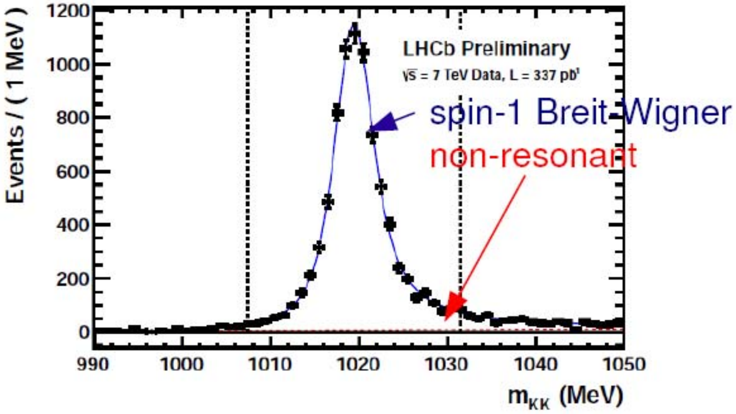


- $J/\psi\phi$: KK-system is almost pure ϕ->KK ("P-wave")

- $J/\psi f0$: angular distributions consistent with scalar f0->$\pi\pi$ ("S-wave")

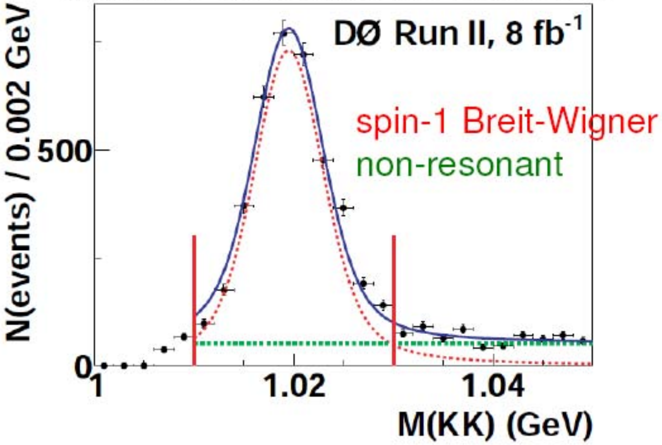
- the 'S-wave' accounts for a small fraction of non-phi in the J/psiKK final state
- interesting enough, LHCb and D0 disagree on fraction of S-wave

mKK in LHCb, background subtracted



LHCb, in range [1008,1032]
- from angle fit: (4 +/- 2)%
- from mass fit: (2+/-1) %

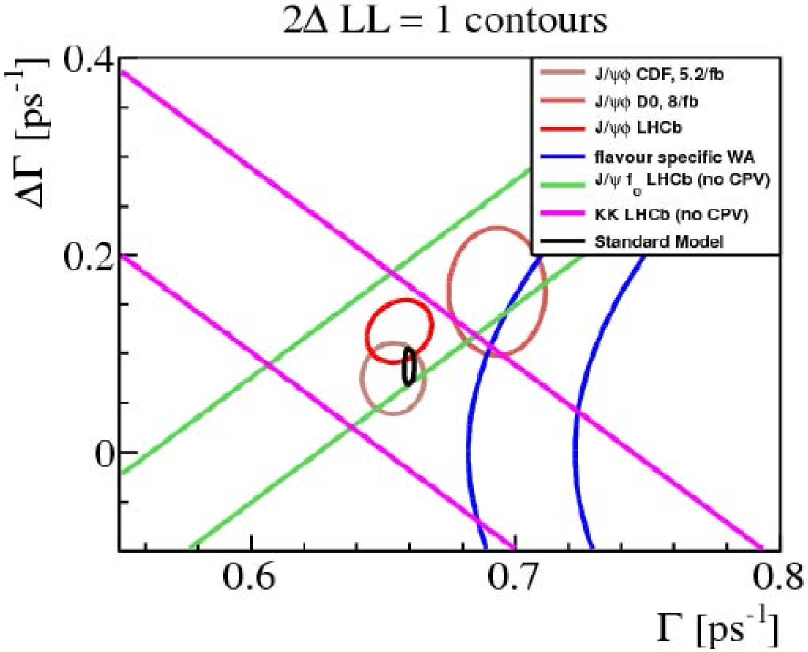
mKK in D0, background subtracted

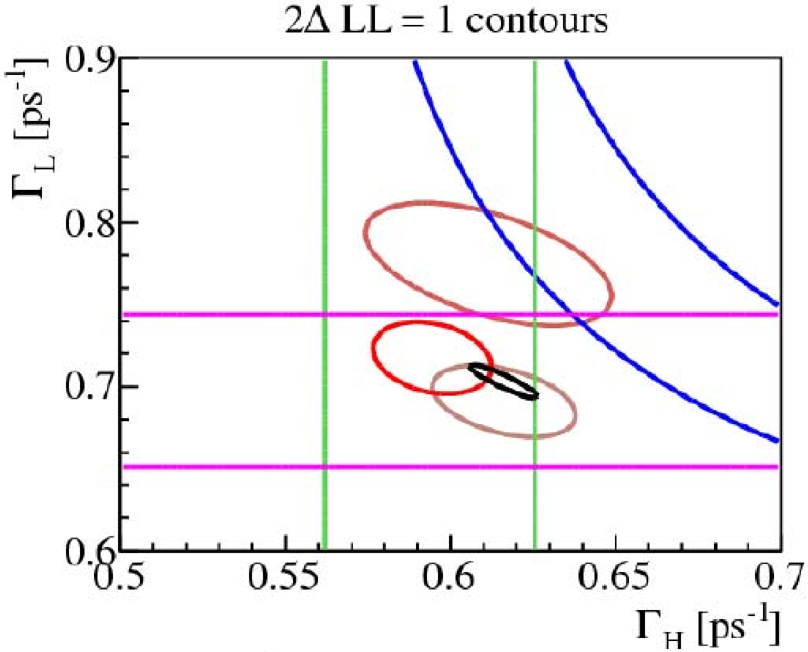


D0, in range [1010,1030]:
- from angle fit: (17+/-4)%
- from mass fit: (14+/-2)%

- CDF measures < 6.7% at 95% CL

- combine various constraints on Γ_s and $\Delta\Gamma_s$ in one graph


2Δ LL = 1 contours


2Δ LL = 1 contours

- 'flavour specific' lifetime (e.g. B_s->$D_s\pi$) constrains:

$$\tau(B_s^0)_{\rm fs} = \frac{1}{\Gamma_s}\frac{1+\left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1-\left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

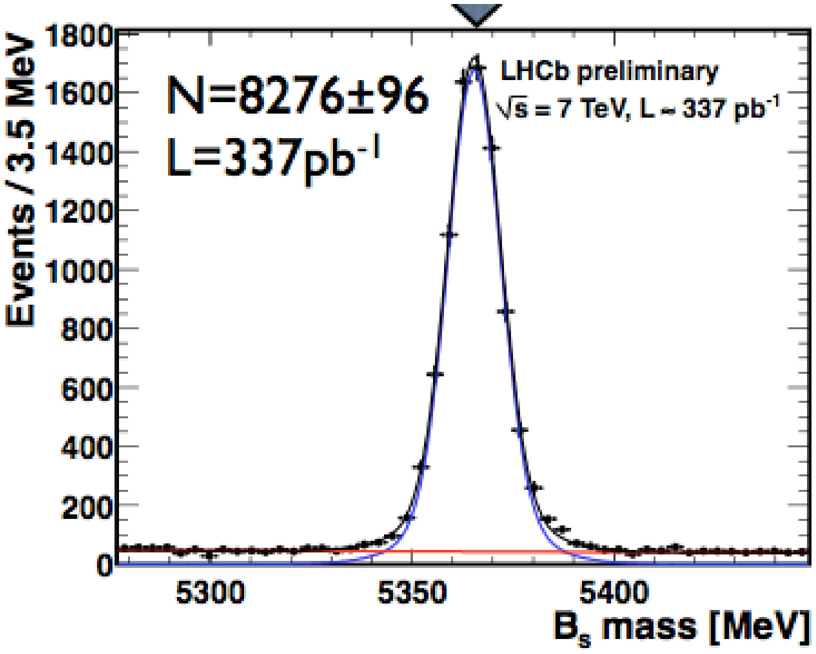
- note
  - flavour specific lifetime doesn't fit very well: high on our agenda
  - KK lifetime uses just 37/pb (LHCb-CONF-2011-018) ... will improve!

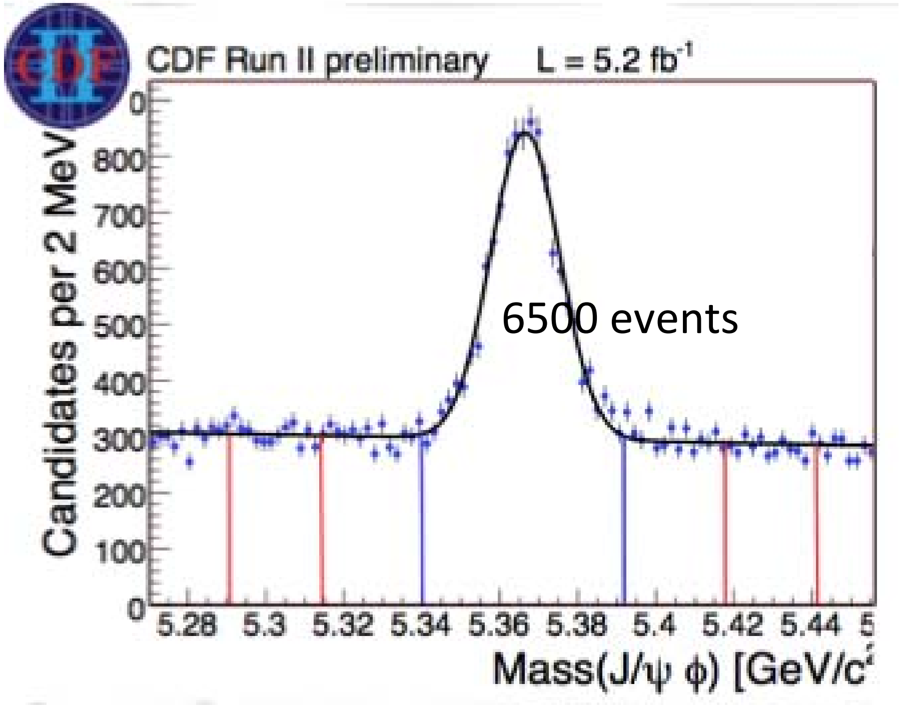
$B_s \rightarrow J/\psi\ \varphi$

Complex analyses :

- time dependent
- Flavour tagging
- full angular analysis for J/ψ φ(B->VV decay)
- should measure at the same time Γ_s and Φ_s

Similar to sin2β at B-Factories using Jpsi Ks



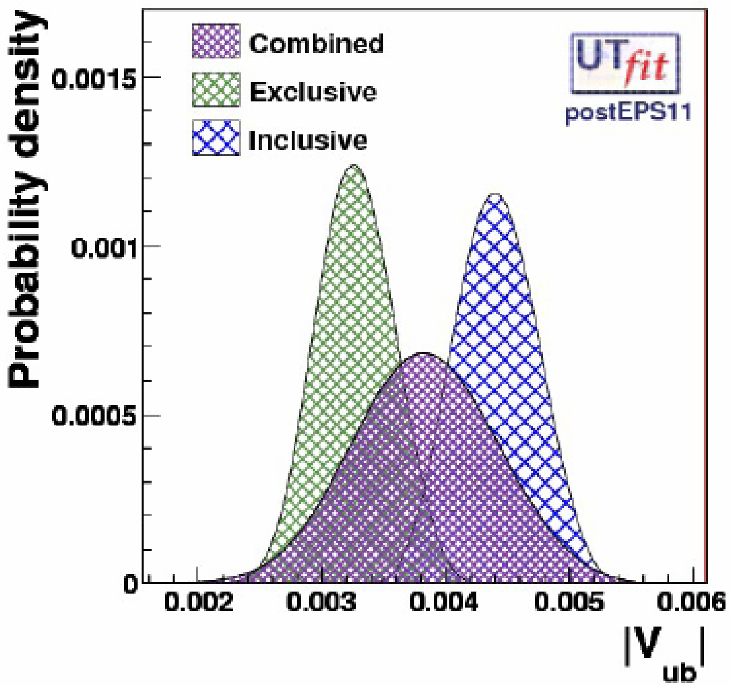


6500 events

	LHCb	CDF
Time resolution	~50 fs	~100 fs
tagging power	2.1 %	~4.8% (OST+SST)

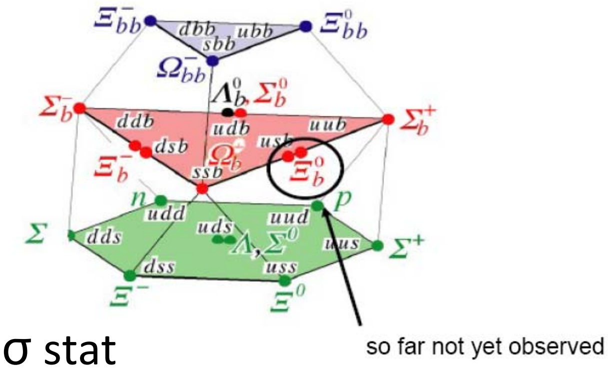
Many other results …

Tension between inclusive and exclusive determination of V_{ub} :

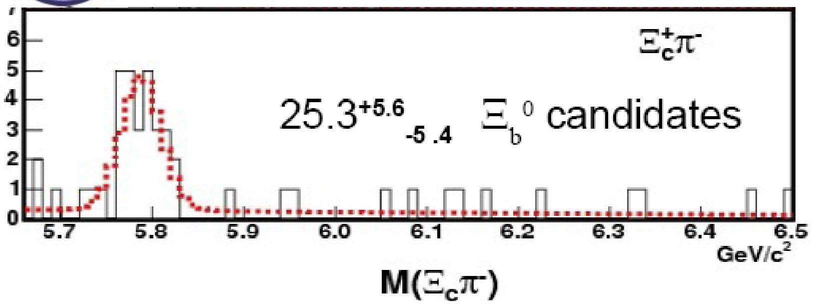


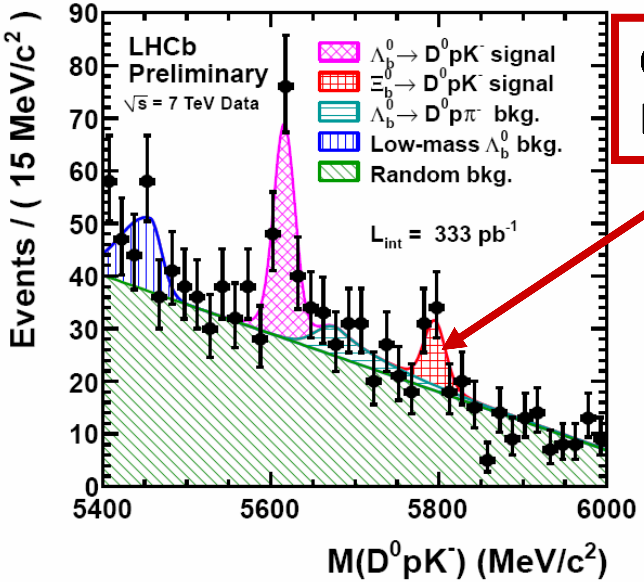
PDG2010 :

$$|V_{ub}|(excl) = (3.38\pm0.36)\times10^{-3}$$
$$|V_{ub}|(incl) = (4.27\pm0.38)\times10^{-3}$$



> 6.8 σ stat





Confirmed by LHCb in D^0 p K^-