B Physics - Status and Prospects

Ulrich Uwer

Heidelberg University

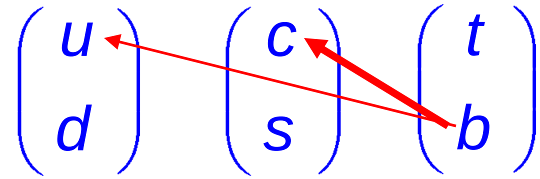
SUSY 2010

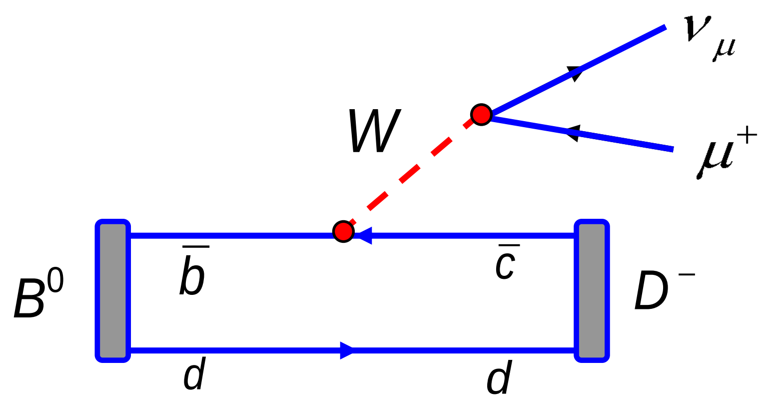
Bonn, August 2010

B Physics

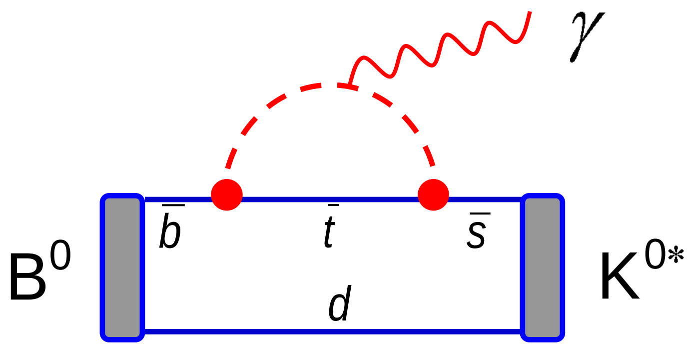
b hadrons:

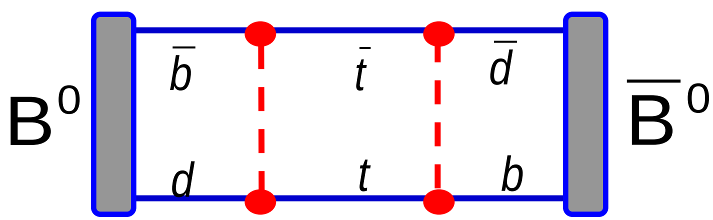
- Tree level decays CKM suppressed.





- Loop corrections important





Precision test of CKM sector & search for New Physics

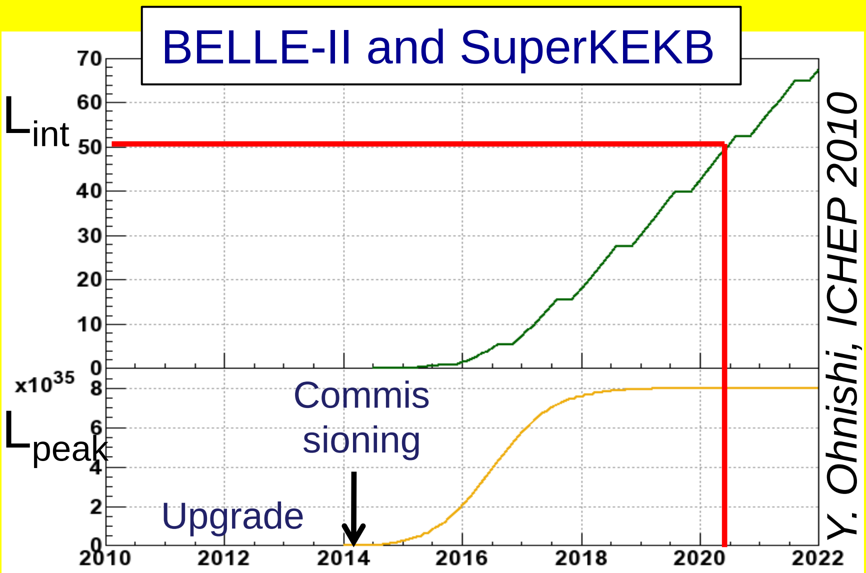
Experiments

B factories at Υ(4S)

770 M BB — 470M BB
14 M B_sB_s
end 06/09 — end 04/08

> 1 ab^{-1}

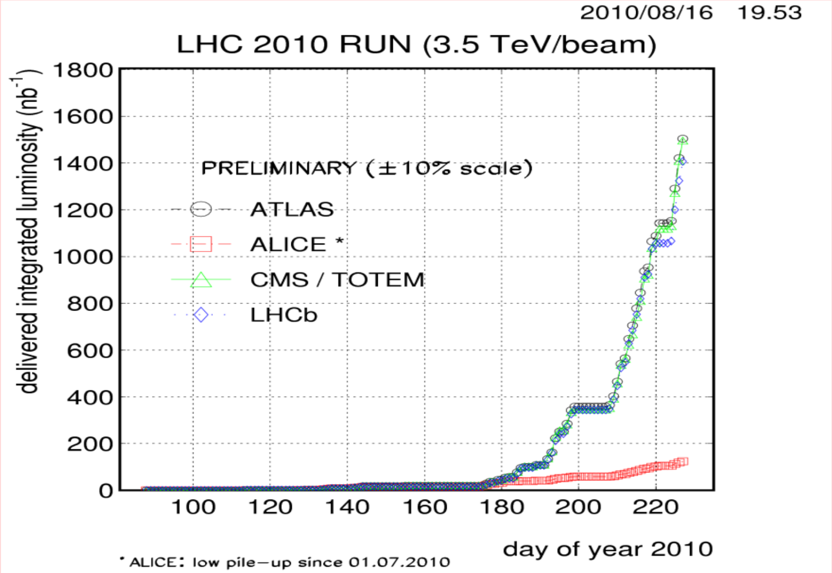
next step: SuperKEKB & SuperB



TEVATRON

- ~9 fb^{-1} for each experim. (up to 6 fb^{-1} analyzed)
- data-taking w/ ~2 fb^{-1} / y

LHC



~3 $\times 10^{11}$ BB until 2011 (1fb^{-1})

Outline

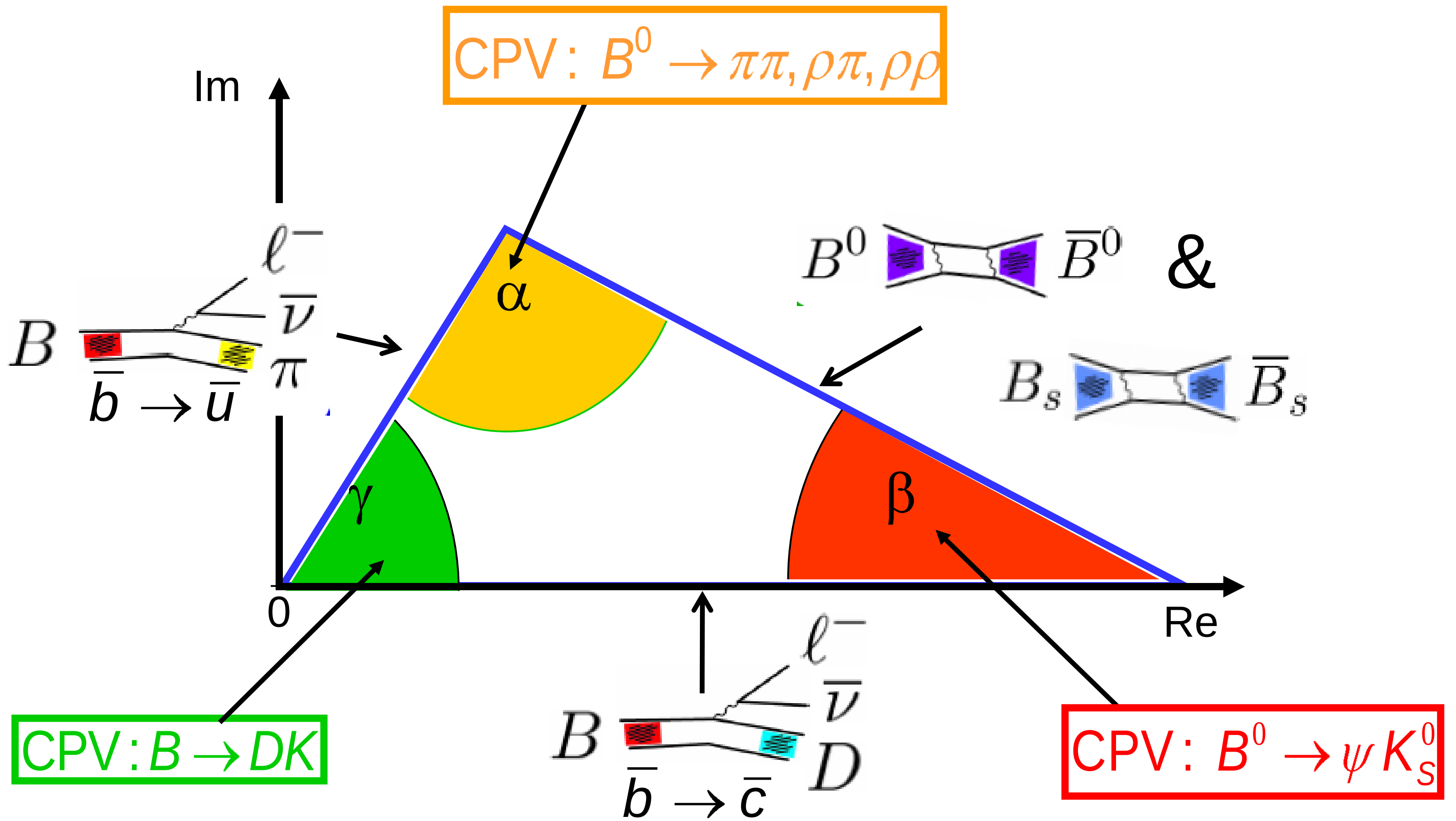
- Status of the CKM Metrology (B_d and B_u)
- New Results in the B_s sector
- Search for New Physics in penguin and very rare decays
- First B results from LHCb

CKM Metrology – B_d and B_u

Unitarity of V_{CKM}:

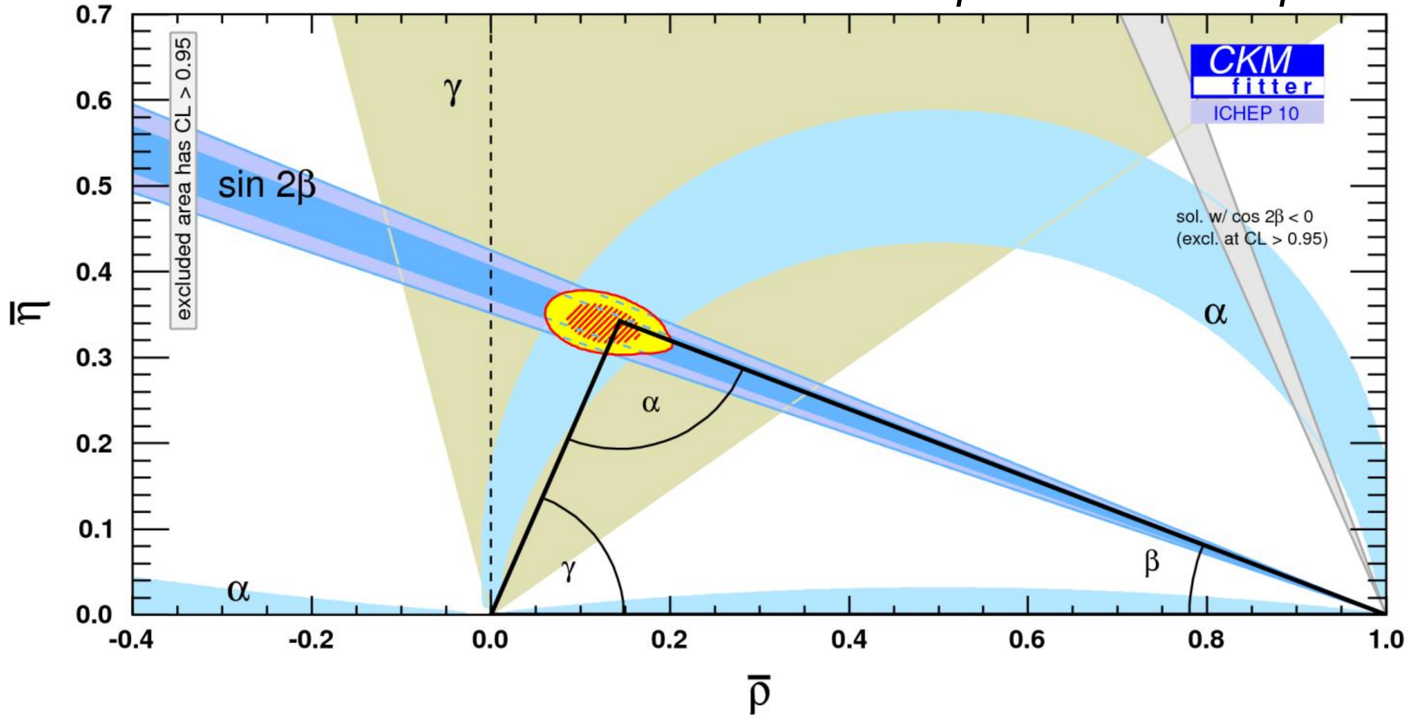
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

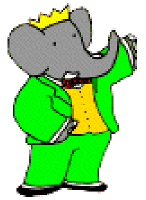
γ β



Status of CKM Phases

http://ckmfitter.in2p3.fr/





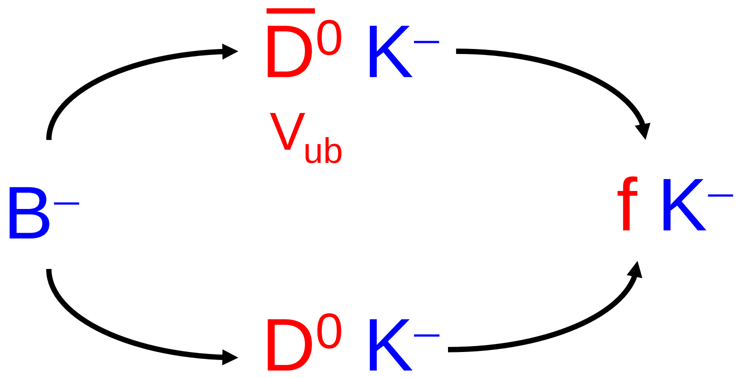
β	$\beta = 21.1^o \pm 0.9^o \quad \sin 2\beta = 0.673 \pm 0.023 \quad (\pm 3.5\%)$
α	$\alpha = (89^{+4.4}_{-4.2})^o$
γ	$\gamma = (73^{+19}_{-24})^o_{CKMfit}$ or $\gamma = (74 \pm 11)^o_{UTfit}$

HFAG WA

updated

Measurement of γ

GLW: Gronau-London, PL B253, 483 (1991);
Gronau-Wyler, PL B265, 172 (1991)
ADS: Atwood-Dunietz-Soni, PRL 78, 3257 (1997)
GGSZ: Giri *et al*, PRD 68, 054018 (2003)



Interference → CP violation → γ

ADS: D^0 decays suppressed ($K^+\pi^-$)
GLW: D^0 decays to CP state ($\pi\pi$,KK)
GGSZ: D^0 decays to $K_s\pi\pi$ (Dalitz)

All methods statistically limited:
very small branching fractions

GGSZ: $\gamma = (68 \pm 14_{stat} \pm 4_{syst} \pm 3_{\mathrm{model}})^o$ — *arXiv: 1005.1096*, *468 M BB*

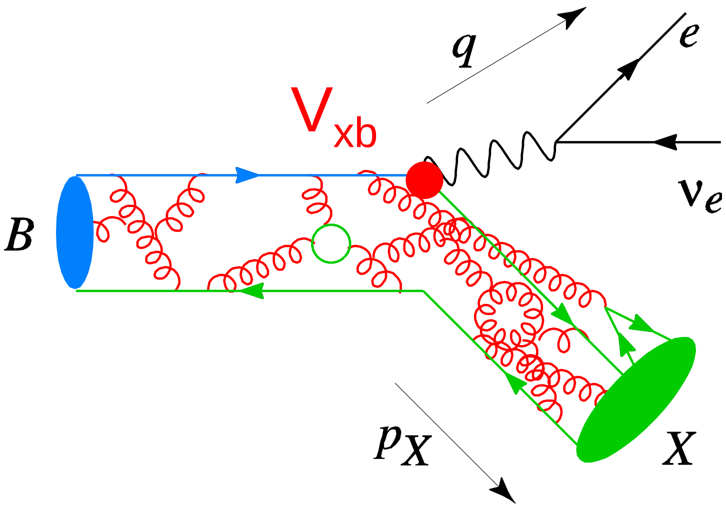
GGSZ: $\gamma = (78.4^{+10.8}_{-11.6\,stat} \pm 3.6_{syst} \pm 8.9_{\mathrm{model}})^o$ — *arXiv: 1003.3360*, *644 M BB*

Combined sensitivity:
S. Haines, ICHEP 2010

$$1\,\mathrm{fb}^{-1} : \sigma_{stat}(\gamma) = 6\ldots8^o$$

$$10\,\mathrm{fb}^{-1} : \sigma_{stat}(\gamma) = 2\ldots3^o$$

$|V_{c(u)b}|$ from semileptonic B decays



$$\Gamma(B \to X_{c(u)} \ell \nu) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{c(u)b}|^2 [1 + A_{ew}] \times A_{QCD}$$

⇨ $|V_{cb}|$ and $|V_{ub}|$

Inclusive: Distributions for $b \to q\, l\nu$ events
Operator Product Expansion in α and Λ/m_b

Exclusive: Measure single channel $B \to X\, l\, \nu$
Form factor (e.g. from Lattice QCD)

Theoretical uncertainties different.

combined effort of theory and experiment

$|V_{cb}|$ from semileptonic Decays

inclusive

$$\Gamma(B \to X_{c(u)} \ell \nu) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{c(u)b}|^2 [1 + A_{ew}] A_{pert} A_{nonpert}$$

$A_{pert} \leftarrow \alpha_s^k$, $A_{nonpert} \leftarrow \left(\frac{1}{m_b}\right)^n$

OPE relates expansion parameters to moments of inclusive distributions:
→ fit of 60 different moments.

PRD 81 (2010) 032003.

$|V_{cb}| = (42.05 \pm 0.45 \pm 0.70) \times 10^{-3}$

exclusive

$B \to D\, l\nu$

PRL 104 (2010) 011802. 460 M BB

$G(1)|V_{cb}| = (42.3 \pm 1.9 \pm 1.4) \times 10^{-3}$

$B \to D^{*-}\, l\nu$

(Dungel, ICHEP 2010, 711 fb^{-1})

$F(1)|V_{cb}| = (34.5 \pm 0.2 \pm 1.0) \times 10^{-3}$

HFAG

$|V_{cb}| = (41.85 \pm 0.43 \pm 0.59) \times 10^{-3}$

± 2 %

$|V_{cb}| =$ HFAG

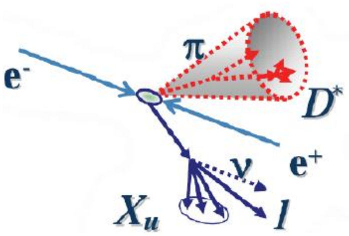
$B \to D\, l\nu$	$(39.2 \pm 1.4 \pm 0.9_{FF}) \times 10^{-3}$
$B \to D^{*-}\, l\nu$	$(39.1 \pm 0.6 \pm 0.8_{FF}) \times 10^{-3}$

not updated

± 3 %

Inclusive determination of $|V_{ub}|$

$$\Gamma(B \to X_u \ell \nu) \approx \frac{1}{50} \Gamma(B \to X_c \ell \nu)$$



Kinematic cuts

Reconst. 2^{nd} B

<u>Theory to extrapolate to full phase space:</u>

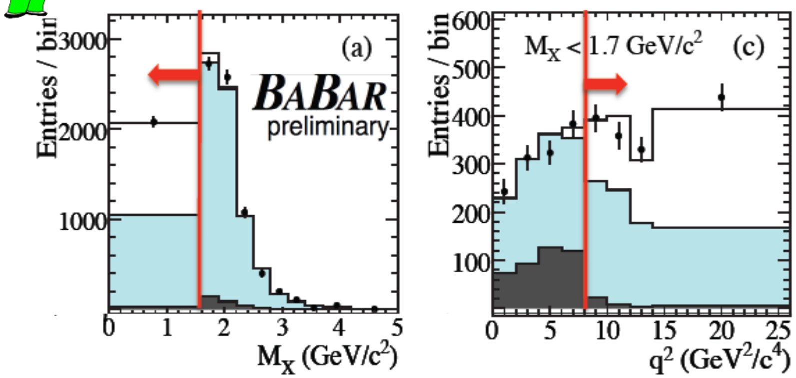
BLNP	PRD 72 (2005) 073006
DGE	arXiv:0806.4524 [hep-ph]
GGOU	JHEP 0710 (2007) 058
ADFR	Eur Phys J C 59 (2009) 831
BLL	PRD 64 (2001) 113004

PRL 104 (2010) 021801

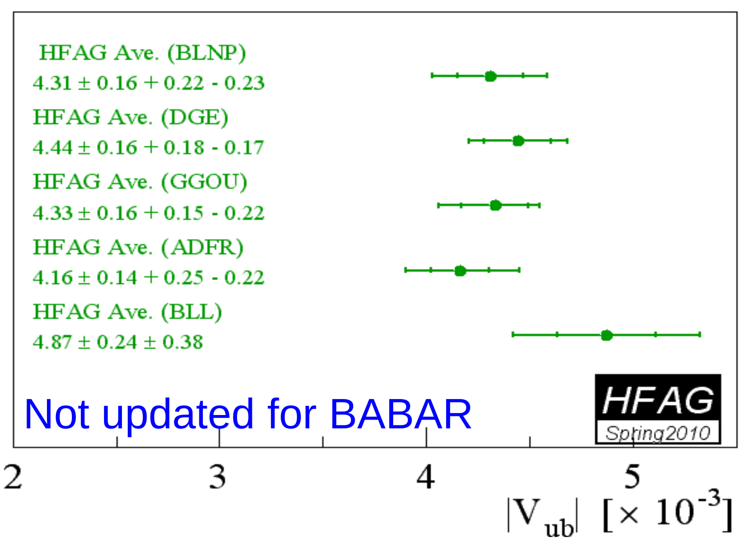
uses 657 M BB events

$|V_{ub}| = (4.46 \pm 0.27_{exp} \pm 0.21_{th}) \times 10^{-3}$ BLNP

BABAR ICHEP 2010 (467 M BB)



$|V_{ub}| = (4.27 \pm 0.23_{exp} \pm 0.26_{th}) \times 10^{-3}$ BLNP



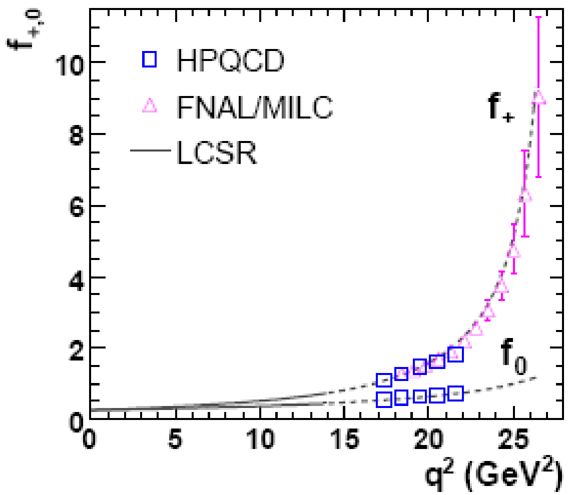
Average of averages:

$|V_{ub}| = (4.37 \pm 0.16_{exp} \pm 0.20_{th}) \times 10^{-3}$

$\pm 6\%$

B. Kowalewski, FPCP 2010

$|V_{ub}|$ from $B \to \pi l \nu$



$$\frac{d\Gamma(B \to \pi l \nu)}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{192\pi^3 m_b^3} \lambda(q^2)^{3/2} |f_+^\pi(q^2)|^2$$

Form Factor calculations:

LCSR: Light Cone Sum Rules

HPQCD: Lattice QCD

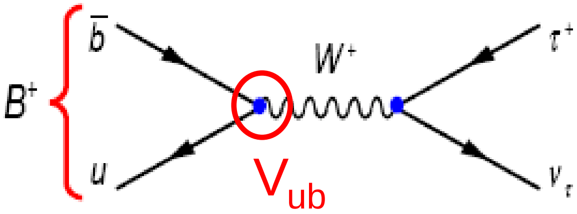
FNAL/MILC: Lattice QCD → fit data & lattice results *PRD 79 (2009)*

	Belle (ICHEP 2010, 605 fb^{-1})	*BABAR (arXiv:1005.3288, 377 M BB)*	
BF =	$(1.49 \pm 0.04 \pm 0.07) \times 10^{-4}$	$(1.41 \pm 0.05 \pm 0.07) \times 10^{-4}$	
$\lvert V_{ub}\rvert$ =	$(3.64 \pm 0.11\ ^{+0.60}_{-0.40}) \times 10^{-3}$	$(3.63 \pm 0.12\ ^{+0.59}_{-0.40}) \times 10^{-3}$	LCSR (q^2<16)
	$(3.55 \pm 0.13\ ^{+0.62}_{-0.41}) \times 10^{-3}$	$(3.21 \pm 0.17\ ^{+0.62}_{-0.41}) \times 10^{-3}$	HPQCD (q^2>16)
	$(3.43 \pm 0.33) \times 10^{-3}$	$(2.95 \pm 0.31) \times 10^{-3}$	FNAL/MILC (full q^2)

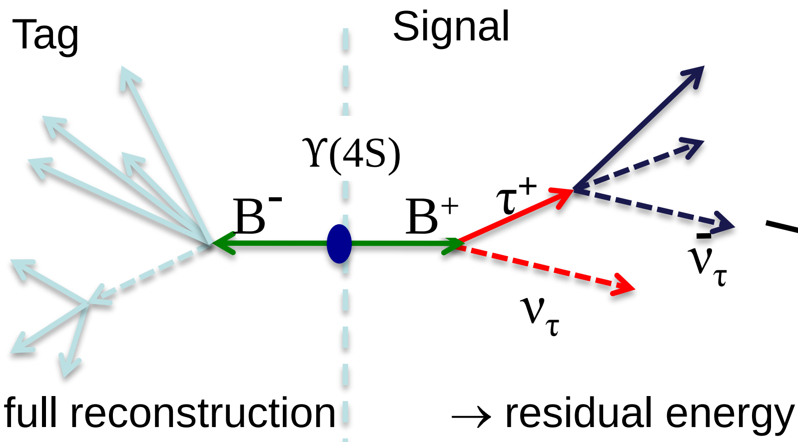
±10%

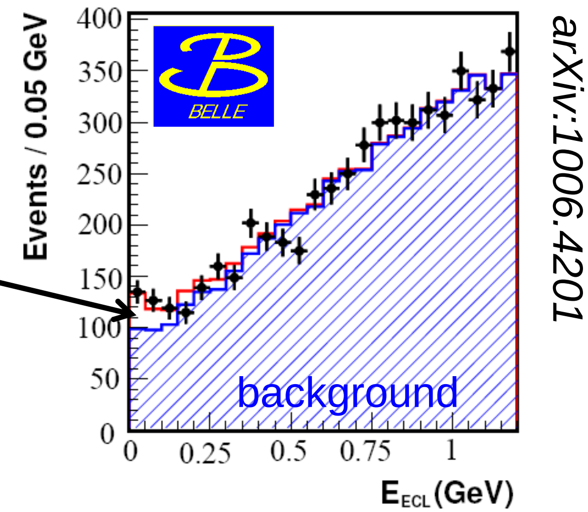
For comparison: $|V_{ub}|_{incl} = (4.37 \pm 0.16_{exp} \pm 0.20_{th}) \times 10^{-3}$ (larger)

$B^+ \to \tau^+\nu$ decays



$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 \boxed{f_B^2 |V_{ub}|^2} \tau_B$$





New

arXiv:1006.4201

$$BR(B \to \tau\nu) = (1.54^{+0.38}_{-0.37}(stat.)^{+0.29}_{-0.31}(syst.)) \times 10^{-4}$$

semilept. tags
657 M BB

$$BR(B \to \tau\nu) = (1.80^{+0.57}_{-0.54}(stat.) \pm 0.26(syst.)) \times 10^{-4}$$

ICHEP 2010

hadronic tags
468 M BB

Results from B→τν

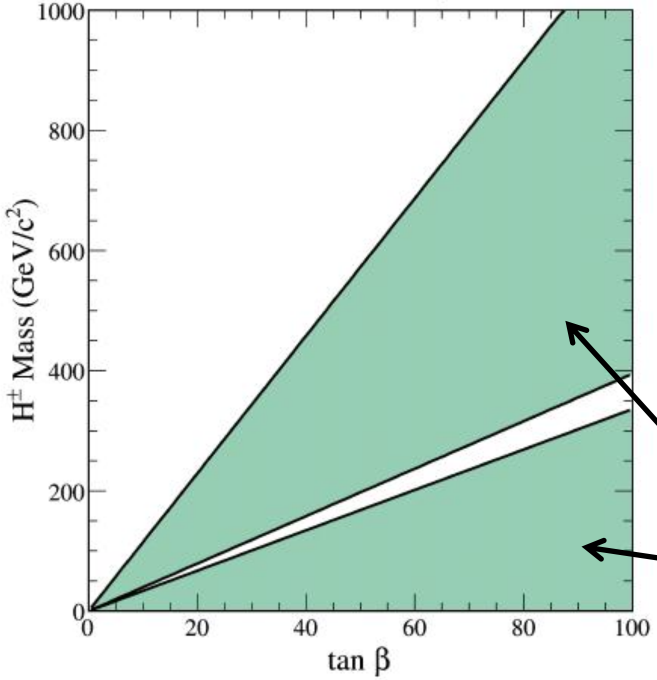
Average $\mathcal{B}(B \to \tau\nu) = (1.68 \pm 0.31) \times 10^{-4}$

Theory $\mathcal{B}(B \to \tau\nu) = (1.20 \pm 0.25) \times 10^{-4}$

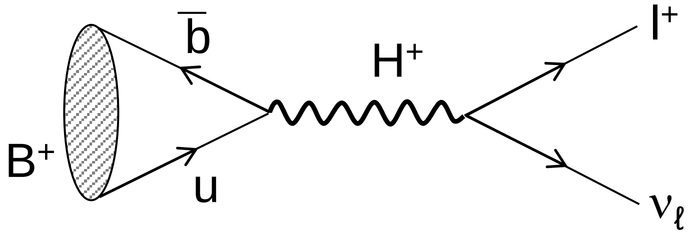
Trabelsi, ICHEP 2010

using f_B (HPQCD), $|V_{ub}|$ incl. HFAG

Trabelsi, ICHEP 2010



Limits on charged Higgs (2HDM II)

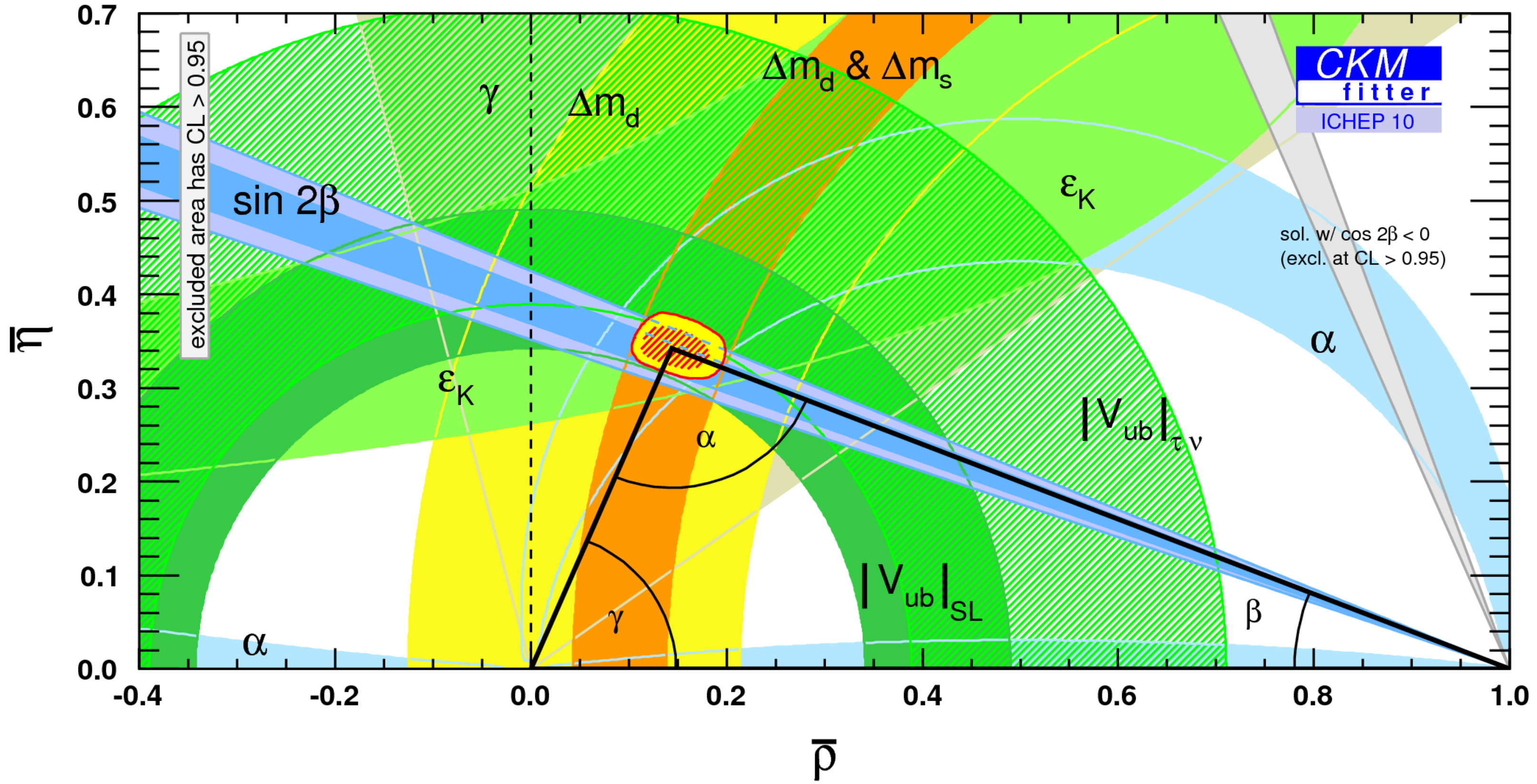


$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}_{SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)^2$$

excluded at 95% CL

Global CKM Fit

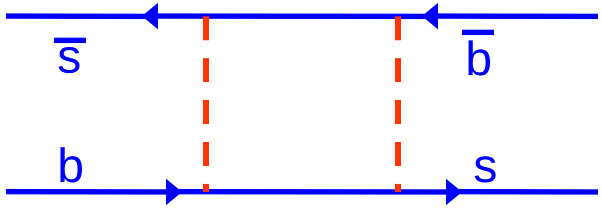
http://ckmfitter.in2p3.fr/



All measurements agree within $\pm 1\sigma$ with fit results except: $\sin 2\beta$ with a 2.6 σ tension and $B(B\rightarrow\tau\nu)$ with 2.8σ tension.

B_s Sector

$\Delta F = 2$

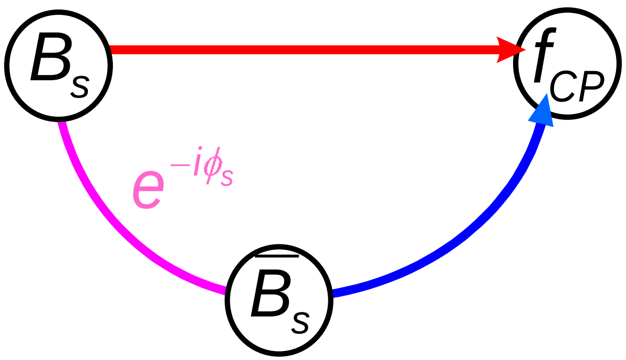


mixing frequency Δm_s

mixing phase ϕ_s

$$A_{SM}(B_s^0 \leftrightarrow \overline{B}_s^0) \sim (V_{tb} V_{ts}^*)^2 \cdot \frac{g^2}{16\pi^2} \frac{m_t^2}{m_W^2}$$

β_s



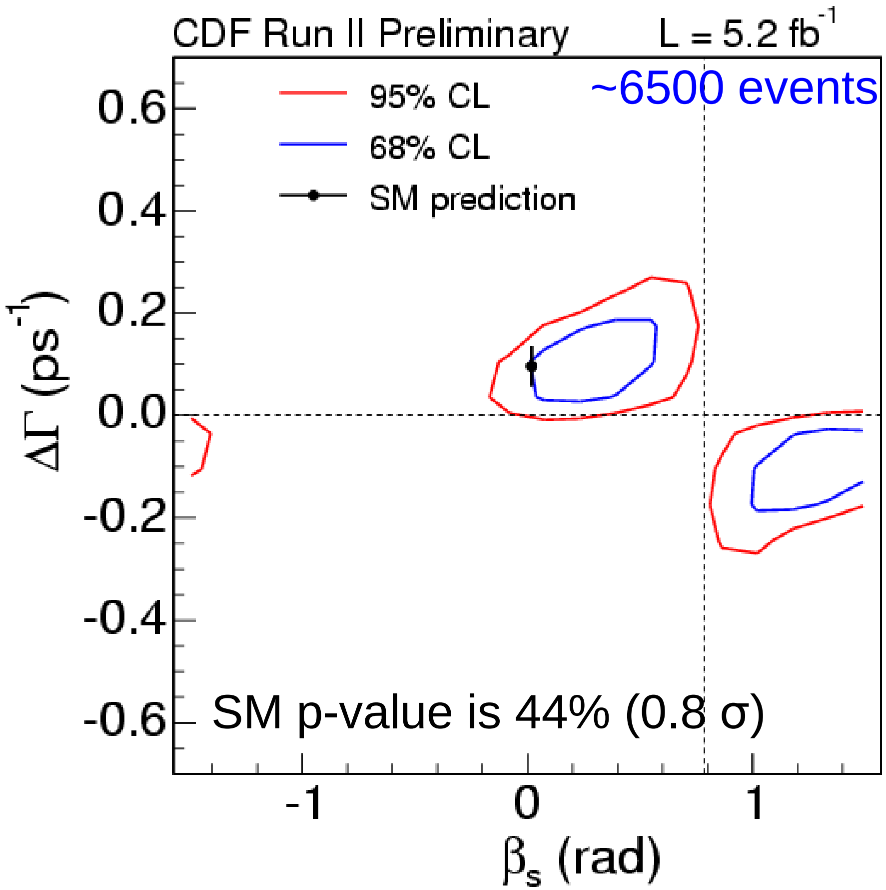
CPV through interference:

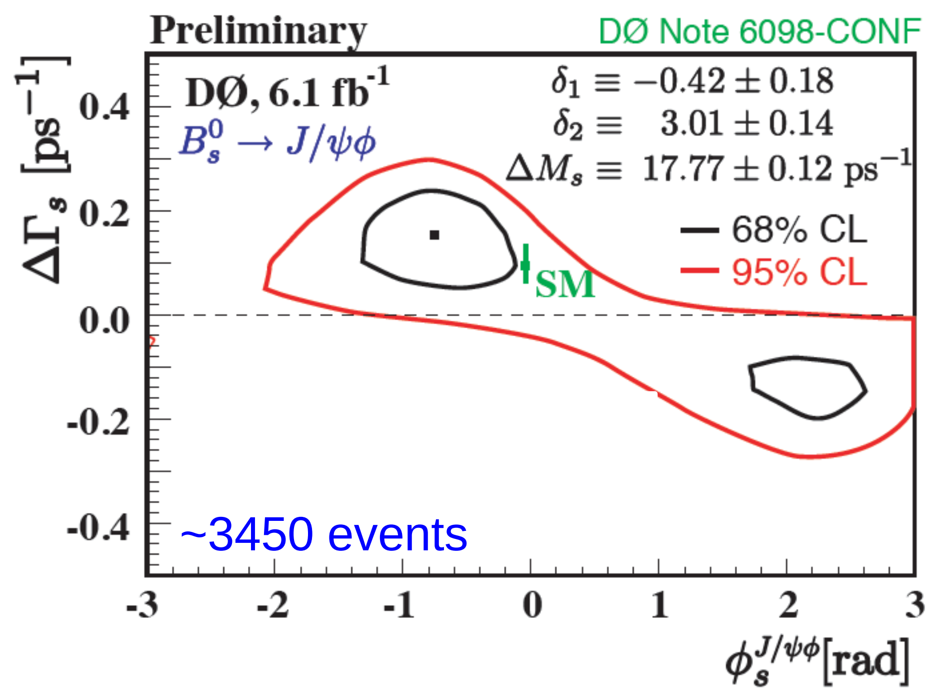
$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0 \to f)(t) - \Gamma(B^0 \to f)(t)}{\Gamma(\overline{B}^0 \to f)(t) + \Gamma(B^0 \to f)(t)} = \sin\phi_s \sin(\Delta m_s t)$$

$$\phi_s^{SM} = -2\beta_s \approx -0.04 \quad V_{ts} = |V_{ts}| e^{i\beta_s}$$

NP: $\phi_s = \phi_s^{SM} + \phi^{NP}$

Mixing Phase ϕ_s from $B_s \rightarrow J/\psi\phi$





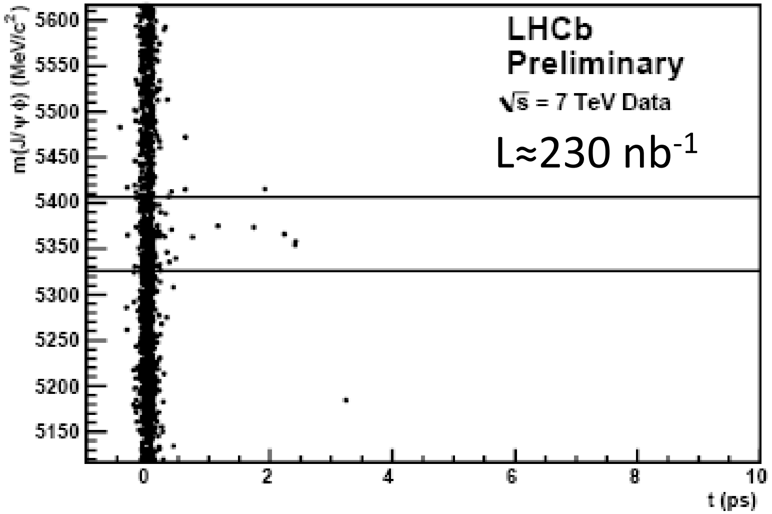
Only opposite flavour tagging

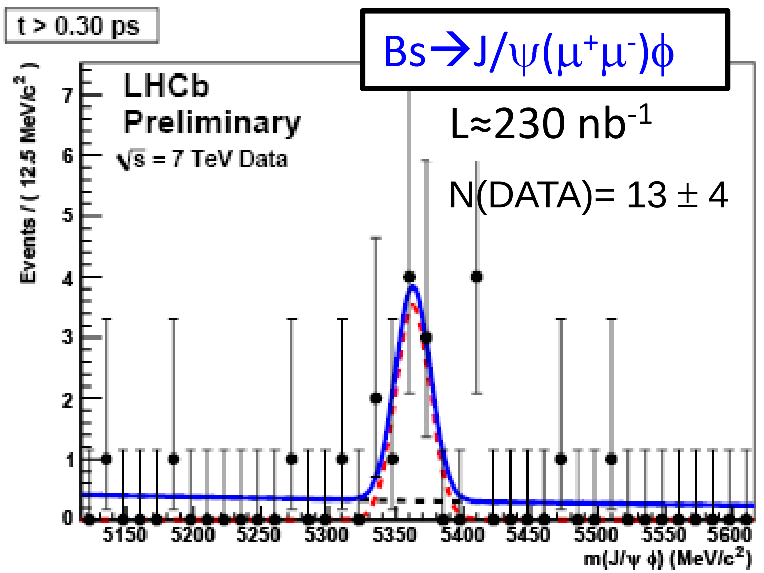
Strong phases from $B^0 \rightarrow J/\psi K^{*0}$

CDF public note 10206

$\phi_s = -2\beta_s$

Prospects for $B_s \to J/\psi\phi$ at LHCb

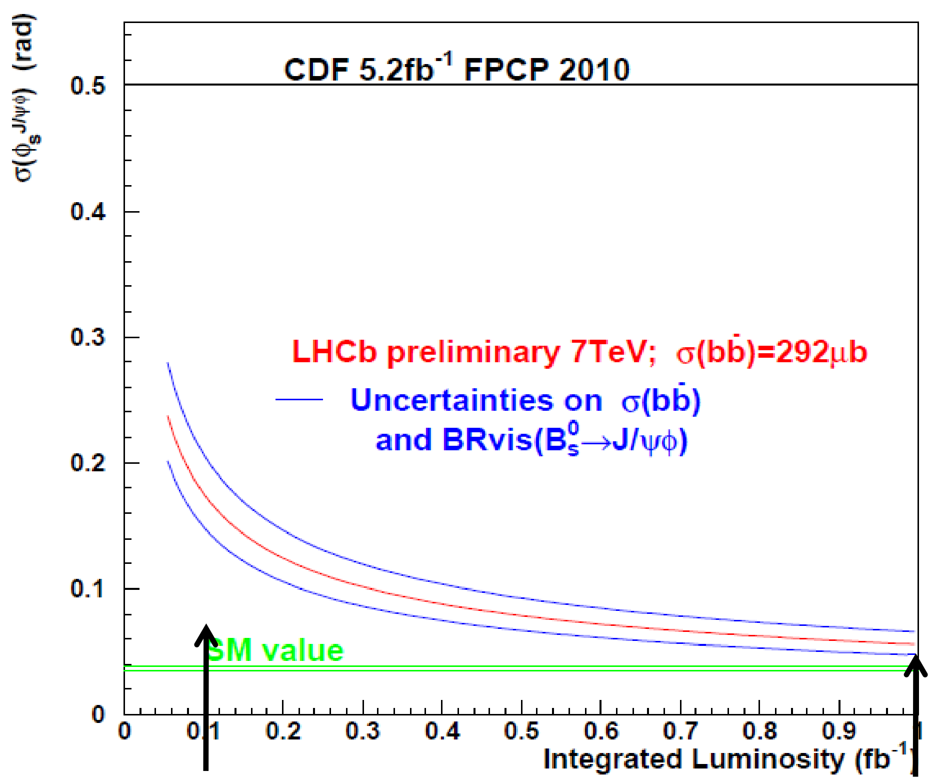




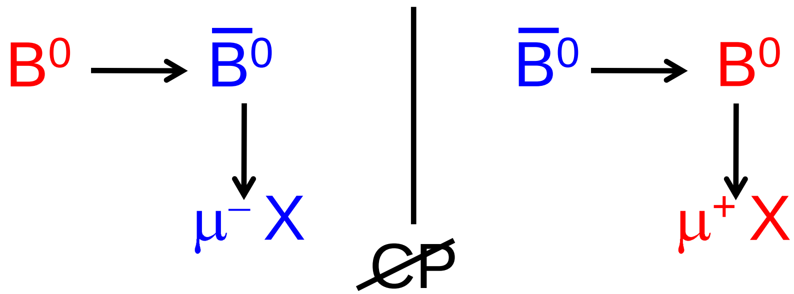
Expectation:

~3500 events / 100 pb^{-1} ($\sqrt{s}$=7TeV)

- Excellent time resolution (40 fs)



CP Violation in Mixing



$$a_{sl}^q \equiv \frac{\Gamma(\overline{B}_q^0 \rightarrow \mu^+ X) - \Gamma(B_q^0 \rightarrow \mu^- X)}{\Gamma(\overline{B}_q^0 \rightarrow \mu^+ X) + \Gamma(B_q^0 \rightarrow \mu^- X)}; \quad q = d, s$$

$$A_{sl}^b = (0.506 \pm 0.043) a_{sl}^d + (0.494 \pm 0.043) a_{sl}^s \qquad a_{sl}^q = \frac{\Delta\Gamma_q}{\Delta m_q} \tan\phi_q$$

$$A_{sl}^{b,SM} = (2.3^{+0.5}_{-0.6}) \times 10^{-4}$$ *A. Lenz, U. Nierste, 2007*

Can be enhanced by New Physics: $\phi_q = \phi_q^{SM} + \phi_q^{NP}$

Two methods to determine A_{sl}

$$A_{sl}^{b}$$

Like-sign dimuon charge asymmetry:

3.7×10^6 like-sign dimuon events

$$A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = (0.564 \pm 0.053)\%$$

$$A = K\, A_{sl}^{b} + A_{bkg}$$

$$A_{sl}^{b} = (-7.36 \pm 2.66_{stat} \pm 3.05_{syst}) \times 10^{-3}$$

Inclusive muon charge asymmetry:

1.5×10^9 incl. muons

$$a = \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)} = (0.955 \pm 0.003)\%$$

$$a = f_s(a_s + \delta) + f_K a_K + f_\pi a_\pi + f_p a_p$$

- δ: μ detect. asym
- a_s: c A_{sl}
- $f_K a_K + f_\pi a_\pi + f_p a_p$: background from K, π, p determined from data

$$a = k\, A_{sl}^{b} + a_{bkg}$$

$$A_{sl}^{b} = (+9.4 \pm 11.2_{stat} \pm 21.4_{syst}) \times 10^{-3}$$

Large correlation between backgr. related uncertainties between both methods

Final A_{sl} result

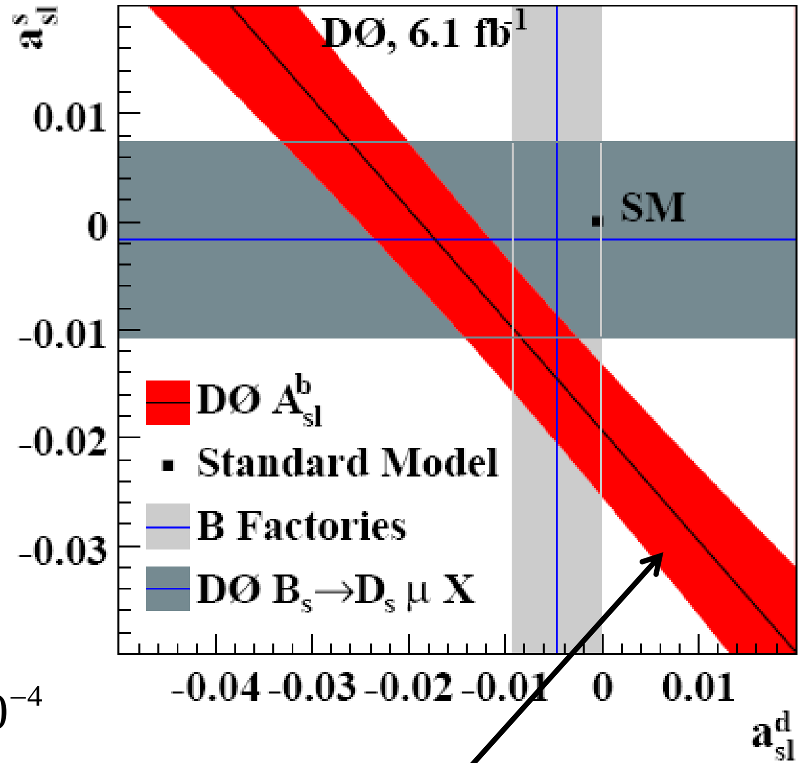
Combination of raw asymmetries:

$$A' = A - \alpha a$$

- bckgr uncertainties partially cancel
- Statistical error increases slightly

$$A_{sl}^{b} = (-9.57 \pm 2.51_{stat} \pm 1.46_{syst}) \times 10^{-3}$$

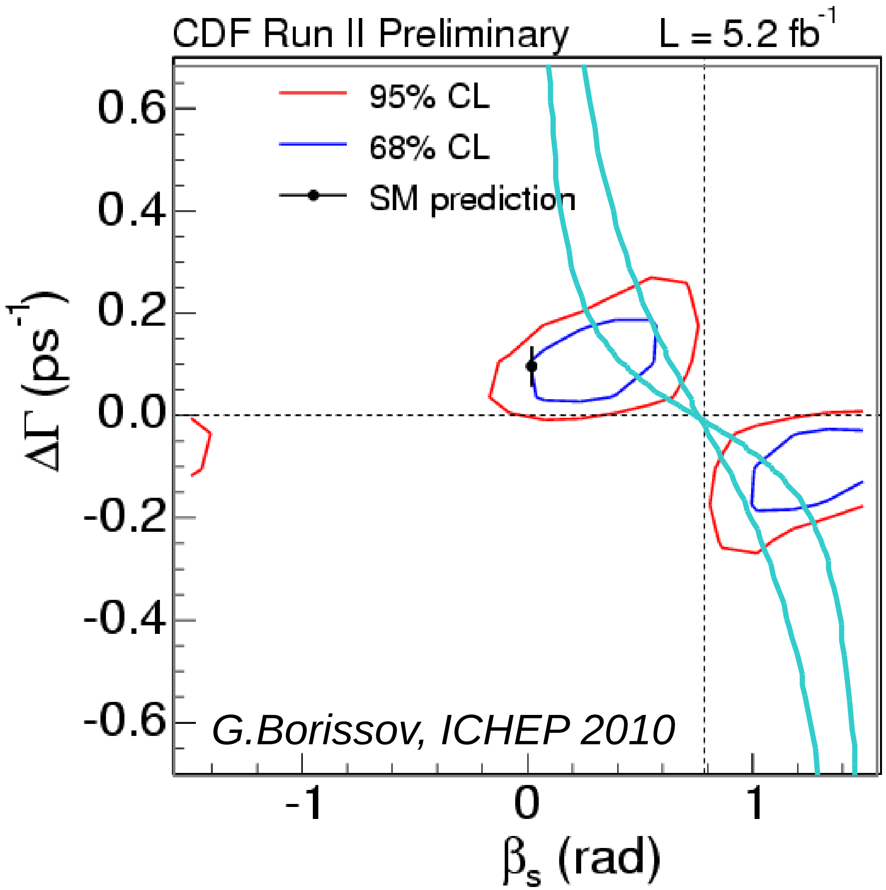
3.2σ deviation form SM $A_{SL}^{b,SM} = (2.3^{+0.5}_{-0.6}) \times 10^{-4}$

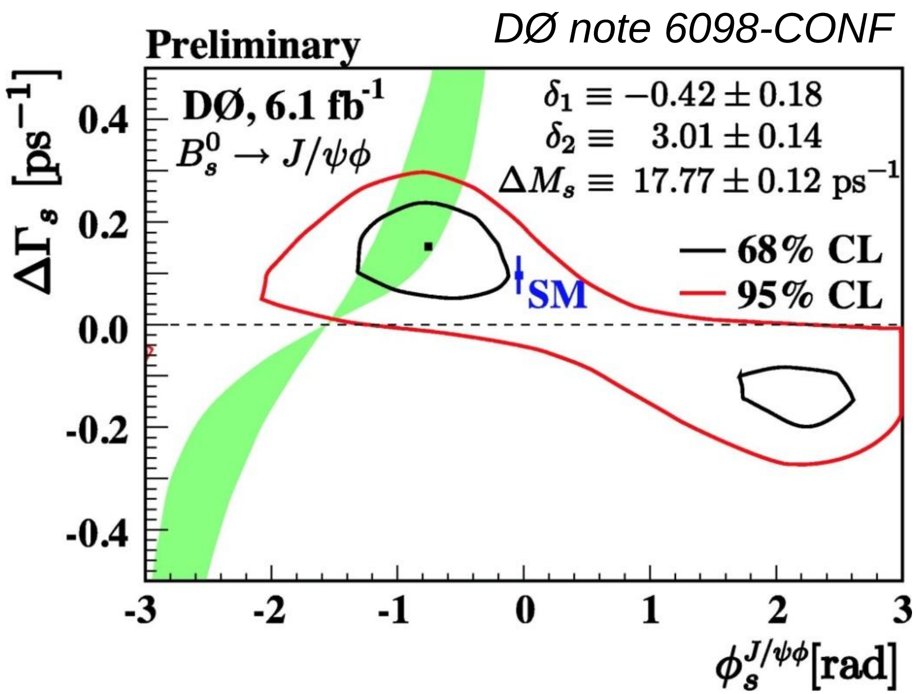


$$A_{sl}^{b} = (0.506 \pm 0.043) a_{sl}^{d} + (0.494 \pm 0.043) a_{sl}^{s}$$

Evidence of anomalous CP-violation in mixing of neutral B mesons.

Compatibility with ϕ_s





$$a_{sl}^{s} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s$$

For interpretation of the result, see talk by U. Nierste.

Prospects at LHCb

Golutvin, ICHEP 2010

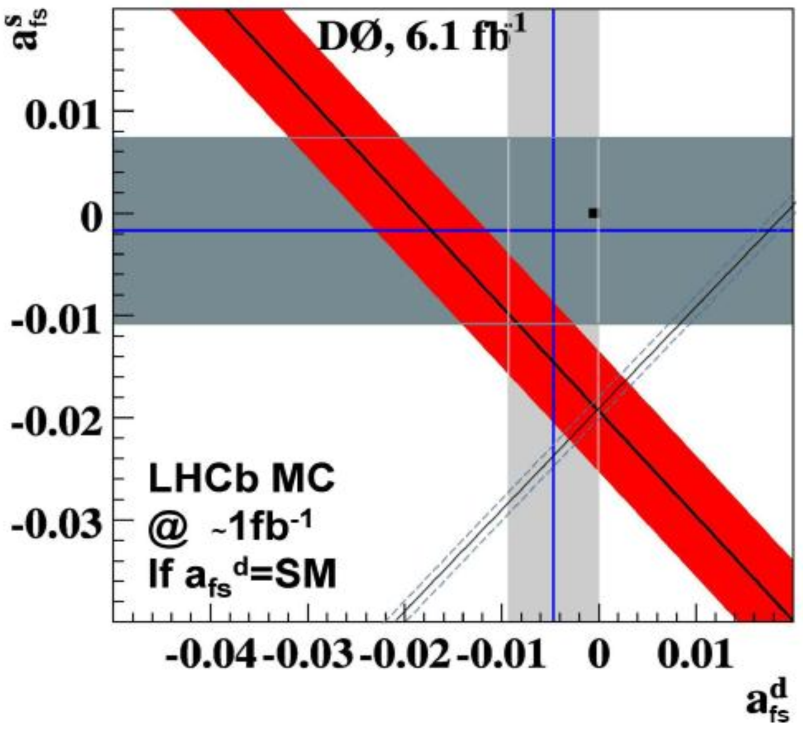
Inclusive method at LHCb due to the prod. asymmetry in pp collisions (~10^{-2}) difficult.

$\Rightarrow$ t-dependent asymmetry difference of semileptonic B decays: $B_s \to D_s(KK\pi)\mu\nu$ and $B^0 \to D^+(KK\pi)\mu\nu$

$$\Delta A_{sl} = \frac{a_{sl}(B_s) - a_{sl}(B_d)}{2}$$

(allows simultaneous fit of prod. asymm.)

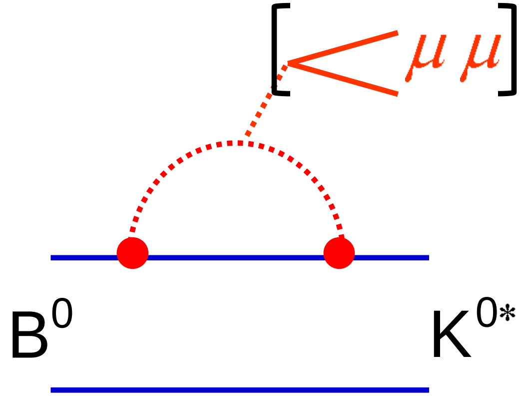
Stat. Error	100 pb^{-1}	1fb^{-1}
ΔA_{fs} (D $\mu\nu$)	2 $\times 10^{-3}$	6.3 $\times 10^{-4}$



- *Provide constrain "orthogonal" to recent D^0 measurement*

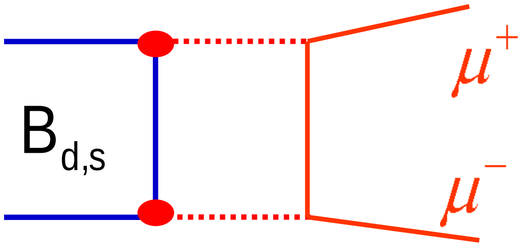
Penguin and very rare FCNC decays

$b \rightarrow s\,\gamma$ penguins



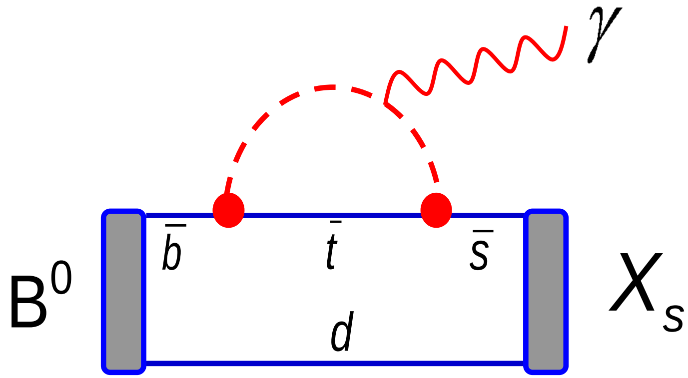
$B_d \rightarrow K^*\gamma$
$B_d \rightarrow K^*\,\mu\mu$

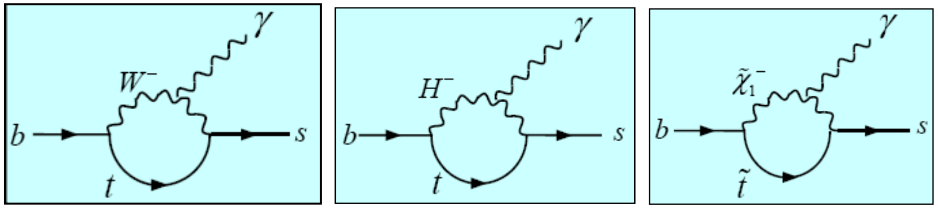
Very rare FCNC proc.



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

$B \to X_s\gamma$





Standard Model

$\mathcal{B}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$

($E_\gamma > 1.6$ GeV)

M. Misiak et al. PRL 98 (2007) 022002

<u>Inclusive measurement:</u>

- Untagged / semilept. tags (2nd B)

for $E_\gamma > 1.7\,\mathrm{GeV}$

$\mathcal{B} = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$

PRL 103 (2009) 241801, 605 fb^{-1}

Average (HFAG) ($E_\gamma > 1.6$ GeV)

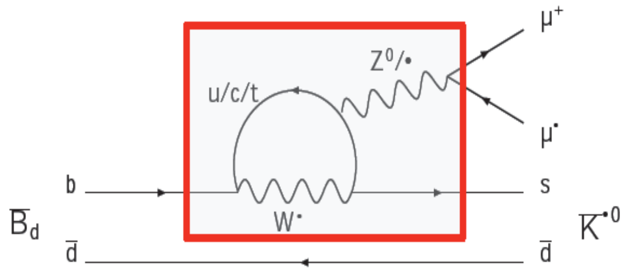
$\mathcal{B}(B \to X_s\gamma) = (3.55 \pm 0.26) \times 10^{-4}$

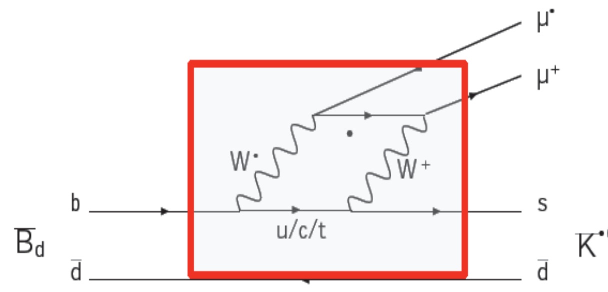
Charged Higgs (2HDM-II) bound:

$M_{H+} > 300$ GeV (95% CL)

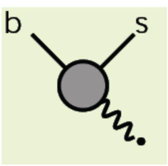
$B^0 \to K^*\mu\mu$

Standard Model

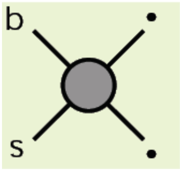




Effective Theory



O_7



$O_9 \quad O_{10}$

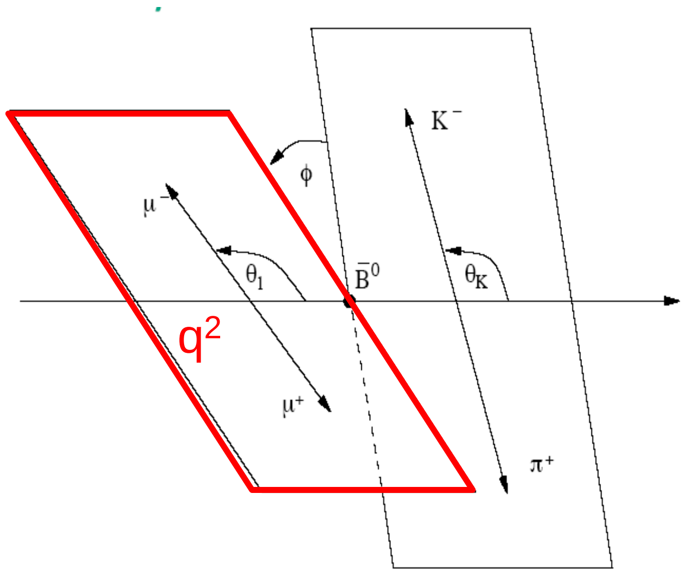
Operator Product Expansion

$$\mathcal{H}_{\text{eff}} = -4\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum C_i(\mu) O_i(\mu)$$

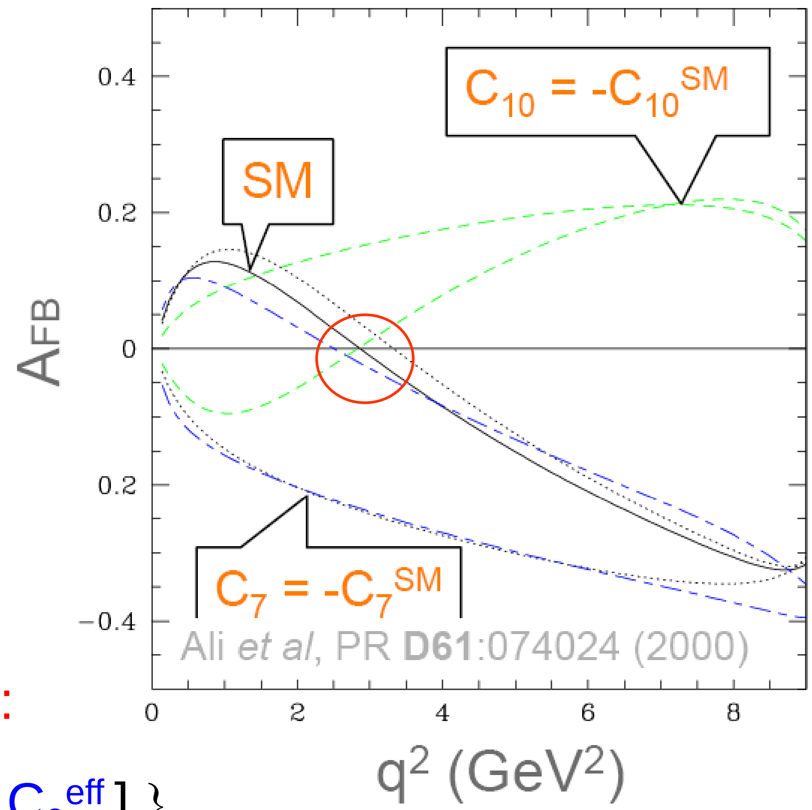
Corresponding Wilson coefficients C_i describe short-range physics.

New Physics in Wilson coefficients $C_i = C_i^{SM} + C_i^{NP}$ or new operators.

NP Sensitivity of Angular Observables



Observables: θ_l, θ_K, ϕ, $m^2_{\mu\mu}$

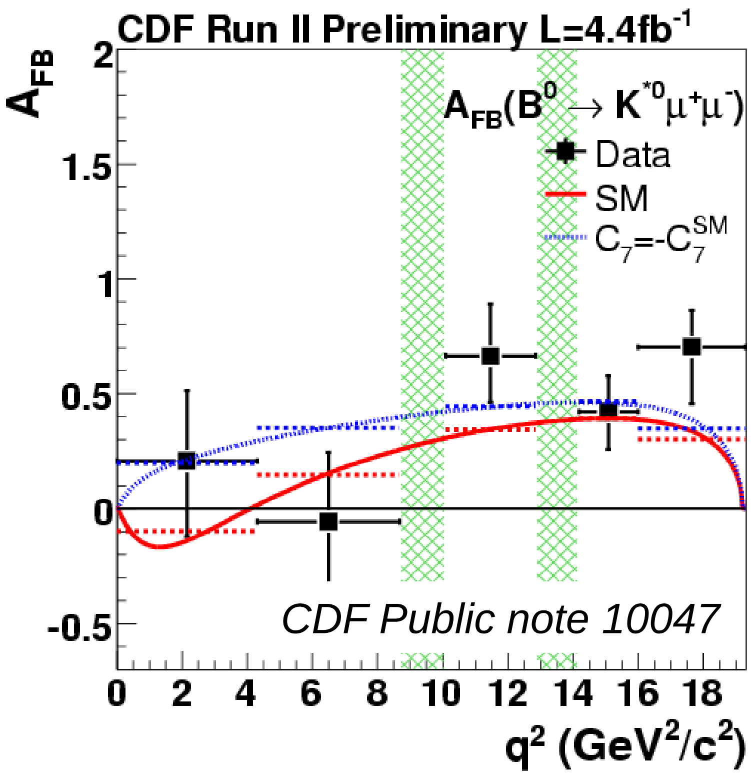


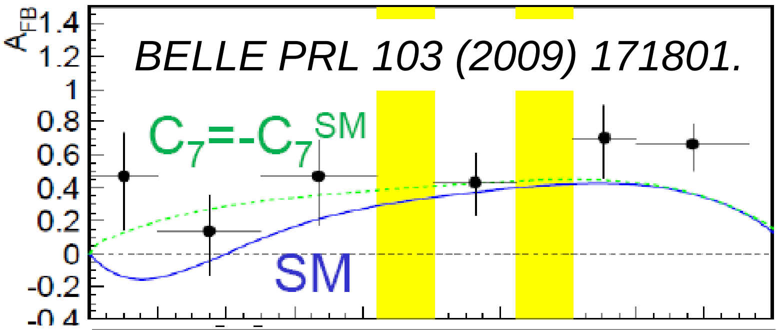
→ μμ forward-backward asymmetry:

$A_{FB}(q^2) \sim -\,\mathrm{Re}\,\{\, C_{10}^{eff*}\, [\, C_7^{eff} + \beta(q^2)\, C_9^{eff}\,]\,\}$

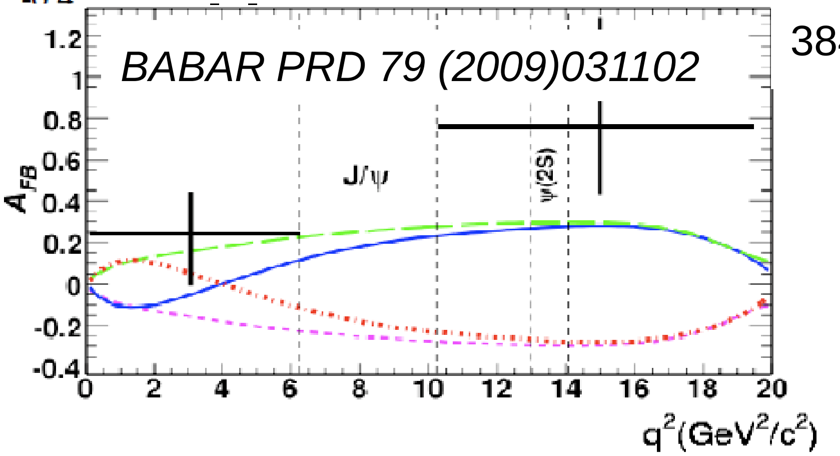
Angular observables offer a powerful test bench for any New Physics model

Status A_{FB} of $B^0 \to K^* \mu\mu$





657 M BB



384 M BB

<u>$B^0 \to K^* \mu\mu$ events:</u>

Belle: ~250 evts

Babar: ~100 evts

CDF: ~100 evts ($4.4\ fb^{-1}$)

~450 evts

G. Mancinelli, ICHEP 2010

<u>LHCb expectation for $1\ fb^{-1}$</u>

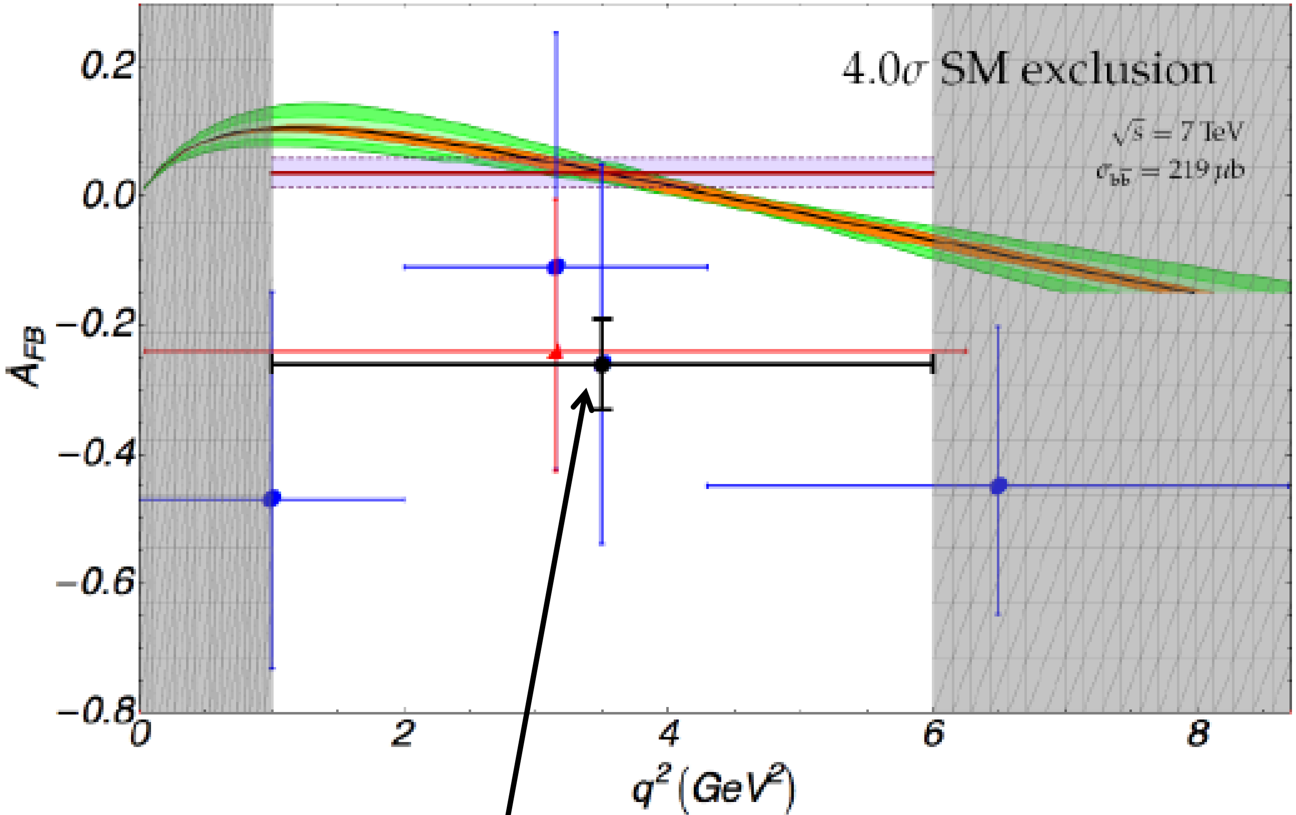
~1400 events w/ B/S~0.25

➡ 140 events for $100\ pb^{-1}$

LHCb Sensitivity for 1 fb^{-1}

G. Mancinelli, ICHEP 2010

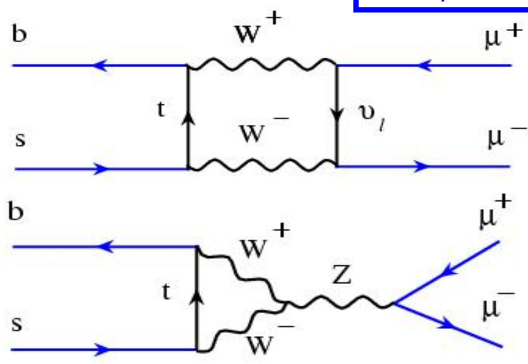
SM prediction
Egede et al
JHEP 0811:032
Belle (2009)
PRL 103 171801
BABAR (2009)
PRD 79 031102
LHCb-MC (projection) at 1.0 fb^{-1}



0.1 fb^{-1}: $\sigma(A_{FB})=0.20$
1.0 fb^{-1}: $\sigma(A_{FB})=0.07$ (end of 2011)

Very Rare Decays - $B_{d,s} \to \mu\mu$

$$B_{d,s} \to \mu^+\mu^-$$

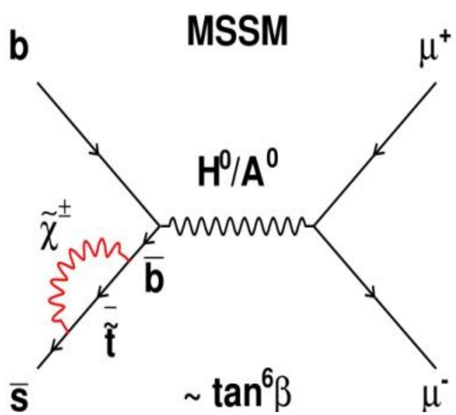


SM: BR($B_s \to \mu^+\mu^-$)= (3.6 0.3)x10^{-9}

BR($B_d \to \mu^+\mu^-$)= (1.1 0.1)x10^{-10}

A. Buras (2009)

Large NP contributions possible



- L = 3.7 fb^{-1}
- Several discriminating variables in NN to improve background reject.
- Limits calculated in several Bins of NN out and $M_{\mu\mu}$

$$\mathrm{Br}(B_s \to \mu^+\mu^-) < 4.3 \times 10^{-8} (95\%\ C.L.)$$
$$\mathrm{Br}(B_d \to \mu^+\mu^-) < 7.6 \times 10^{-9} (95\%\ C.L.)$$

CDF Public note 9892

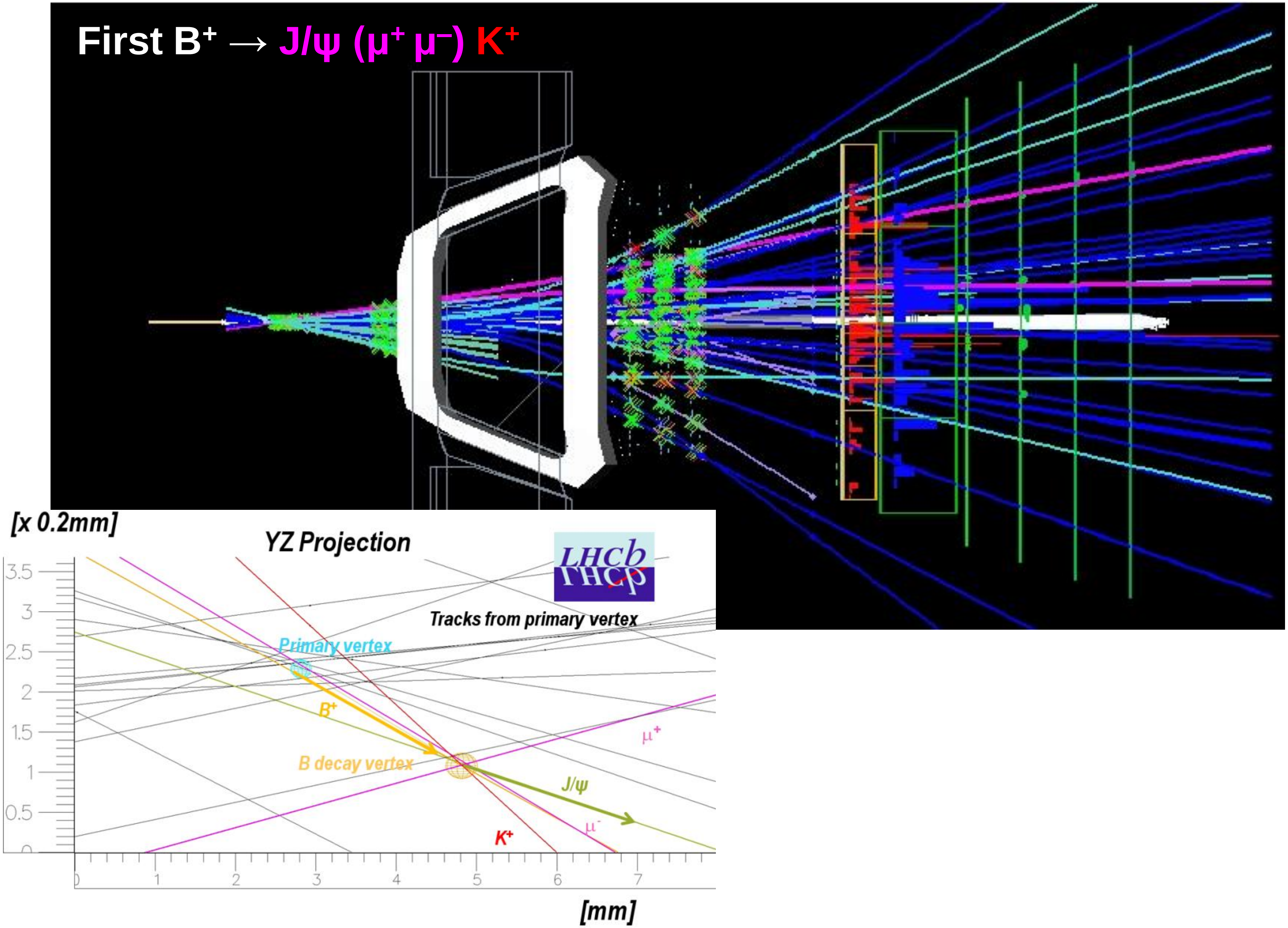
- L = 6.1 fb^{-1}
- Baysian NN instead of likelih. ratio
- Limits calculated in several Bins of BNN out and $M_{\mu\mu}$

$$\mathrm{Br}(B_s \to \mu^+\mu^-) < 5.1 \times 10^{-8} (95\%\ C.L.)$$

arXiv:1006.3469

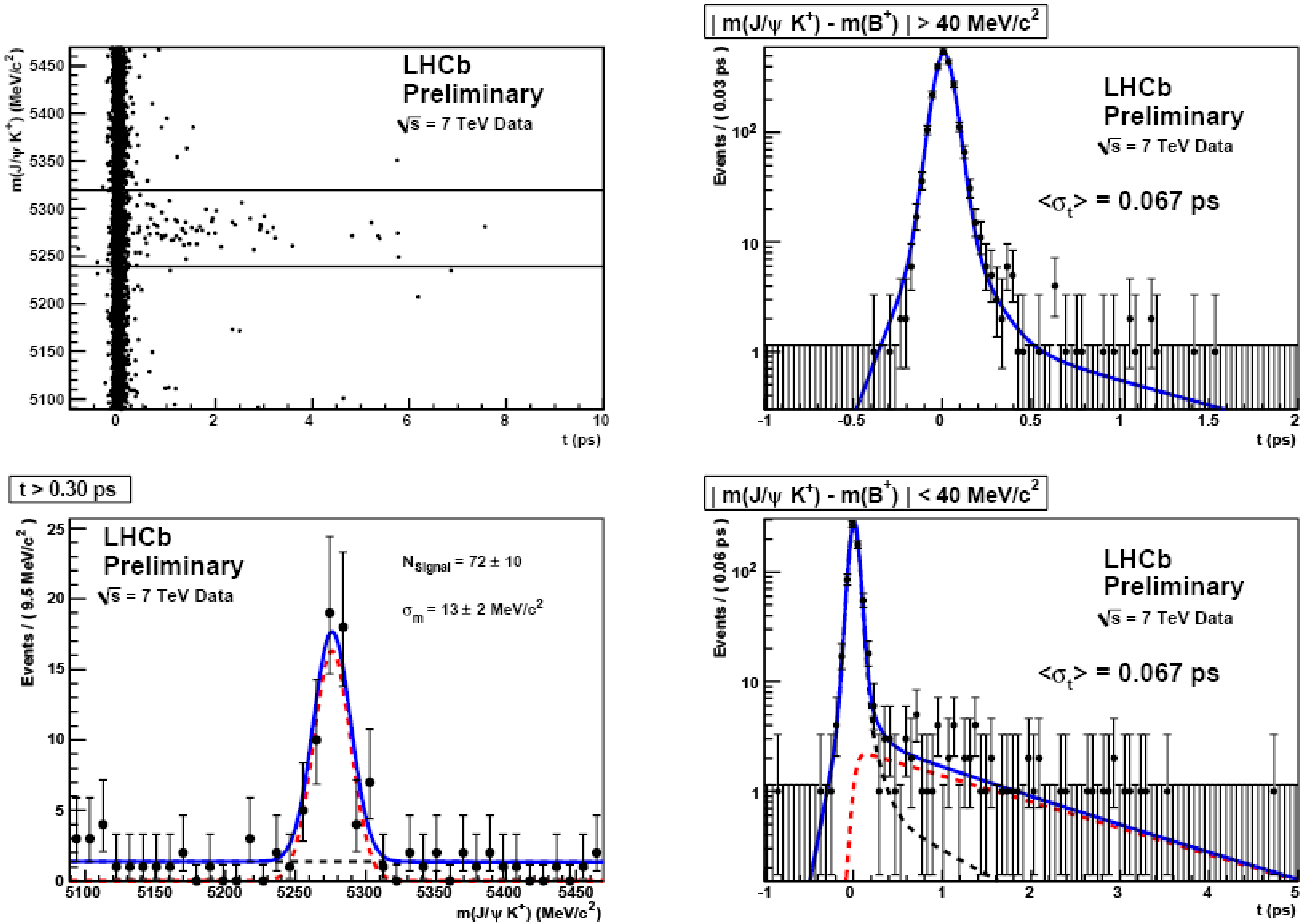
Expect: < 6×10^{-8} (90% CL) 1fb^{-1}

First B results from LHCb



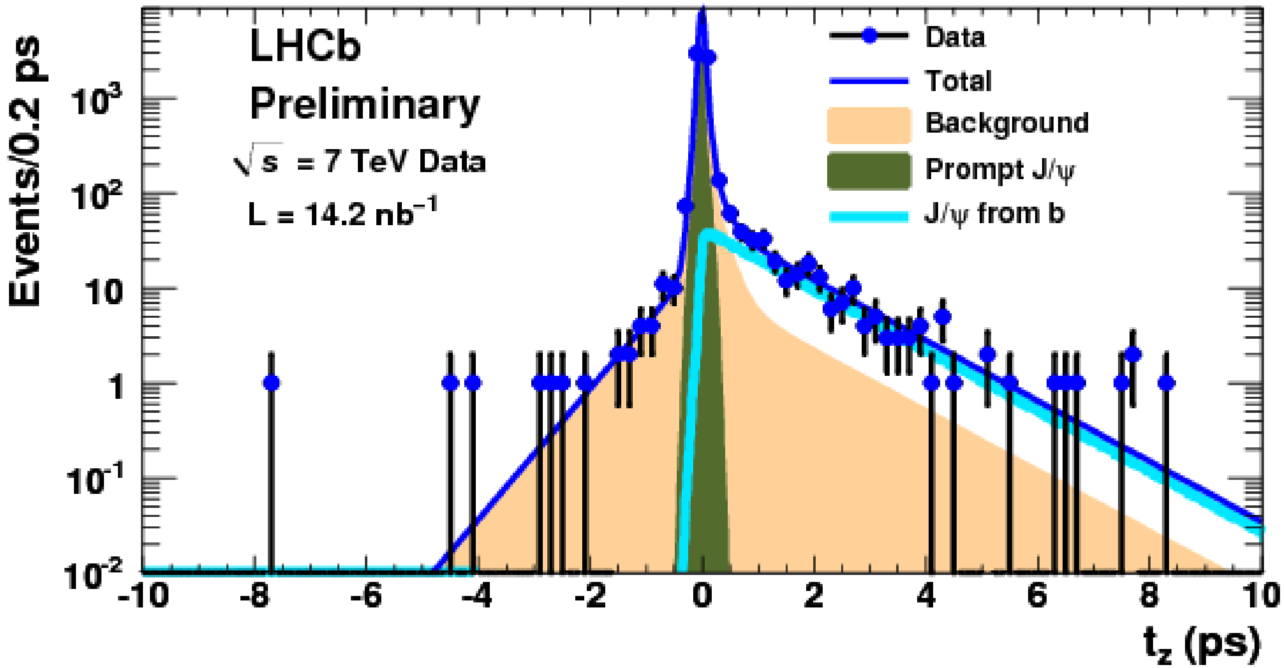
$B \to J/\psi K^+$

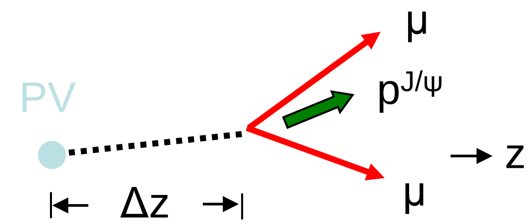
$230\ nb^{-1}$



J/ψ(μμ) +X events

LHCb ICHEP 2010





B fraction f_b = (11.1 ± 0.8) %

σ(J/ψ from b, $p_T^{J/\psi}$ <10 GeV/c, 2.5< $y^{J/\psi}$ <4) = 0.81 ± 0.06 ± 0.13 μb

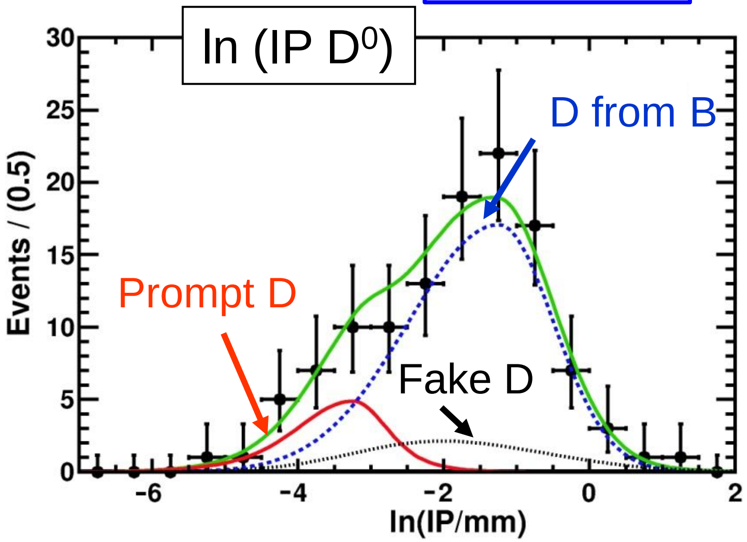
⇩ extrapolation using Phytia

$\sigma(pp \rightarrow H_b X;\ 2<\eta_b< 6)$ = 84.5 ± 6.3 ± 15.6 μb

$b\bar{b}$ cross section from $B \to D^{(*)}\mu\nu X$

LHCb ICHEP 2010

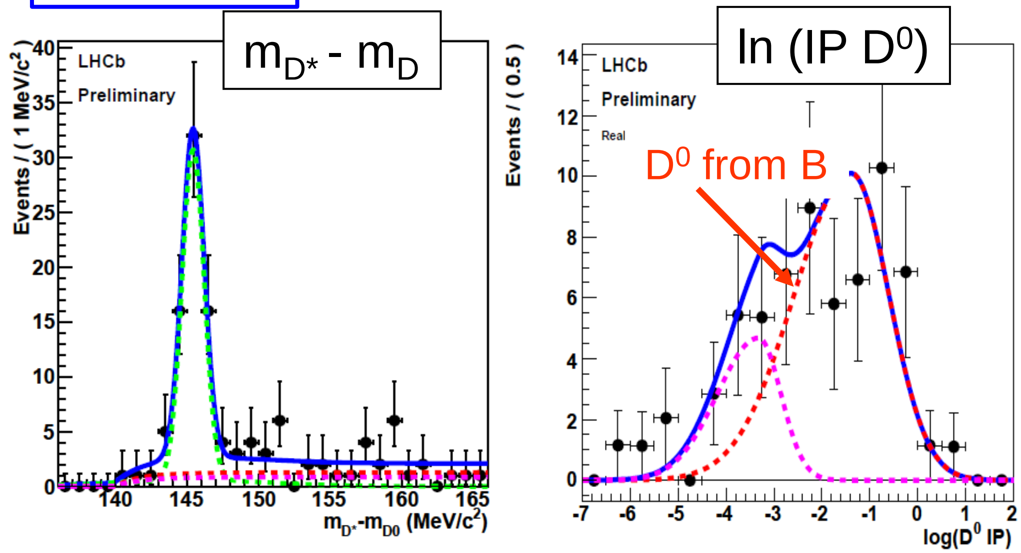
$B \to D^{*}\mu\nu X$



$\sigma\,(pp \to H_b X;\, 2 < \eta < 6) =$

$74.9 \pm 5.3 \pm 12.8$ μb

$B \to D^{*}\mu\nu X$



$\sigma\,(pp \to H_b X;\, 2 < \eta < 6) =$ $73 \pm 12 \pm 17$ μb

Average of 3 measurements →

η	*LHCb preliminary*	*Theory 1*	*Theory2*
2-6	77.4 4.0 11.4 μb	89	70
all	292 15 43 μb	332	254

LHCb assumed ~250 μb

Theory 1: Nason, Dawson, Ellis

Theory 2: Nason, Frixione, Mangano and Ridolfi

Conclusion & Outlook

- CKM mechanism identified as primary source for CPV in the quark sector. Within uncertainties, there is still room for NP.

  Tensions (2.6σ for sin2β and 2.8σ for $B \to \tau\nu$) in the CKM fits.

- B_s sector:
  SM deviation observed previously for B_s mixing phase becomes less significant. Errors are very large.

  Hint for NP: D0 observes anomalous large CPV in mixing.

- "Discovery channels" $B \to K^*\mu\mu$ and $B \to \mu\mu$ are limited by statistics.

- *LHCb* has exciting prospects for 1 fb^{-1} data sample expected for 2011:

  First results confirm *LHCb* trigger & detector concept and simulation.