Beauty and Charm Physics

SPSC Villars meeting

26 September 2004

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CERN

and

Swiss Federal Institute of Technology Lausanne

(b and c quarks)

b- and c- hadrons

production spectroscopy weak decays

(b and c quarks)
b- and c- hadrons

production spectroscopy weak decays

structure functions
parton-parton scattering
QCD radiative corrections
higher twist
heavy quark fragmentation
etc.

(b and c quarks)

b- and c- hadrons

production spectroscopy weak decays

lattice
quark potential
confinement force
etc.

(b and c quarks)

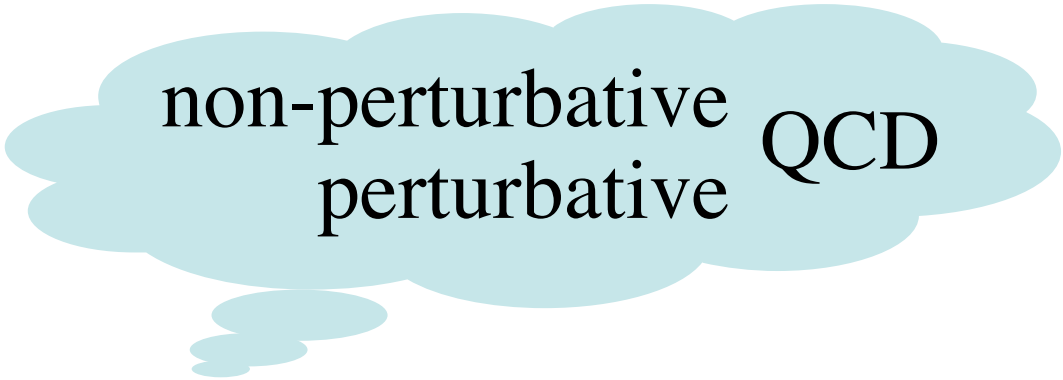
b- and c- hadrons

production spectroscopy weak decays

heavy quark effective the.
chiral perturbation
factorization
p-QCD
lattice
QCD radiative correction
etc.

(b and c quarks)
b- and c- hadrons

production spectroscopy weak decays



(b and c quarks)
b- and c- hadrons

production spectroscopy weak decays

extraction of the
CKM elements V_{ij}

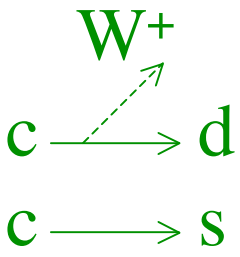
-test of the CKM picture
-search for new physics

CKM matrix: b and c quarks

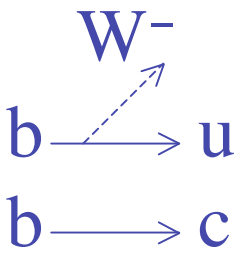
$$\begin{matrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{matrix}$$

CKM matrix: b and c quarks

Tree level: first order weak interactions

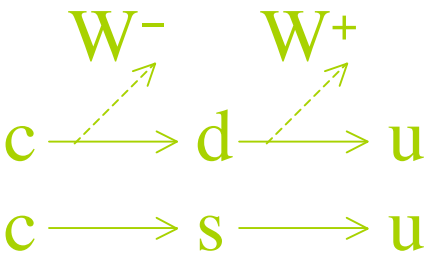


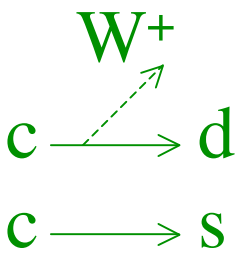
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



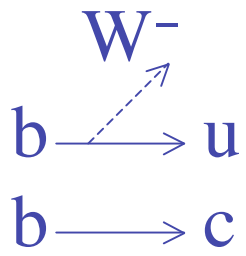
CKM matrix: b and c quarks

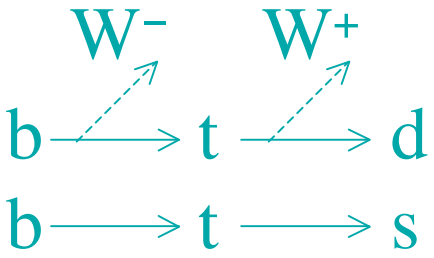
Tree level: first order weak interactions
Loop level: second order weak interactions





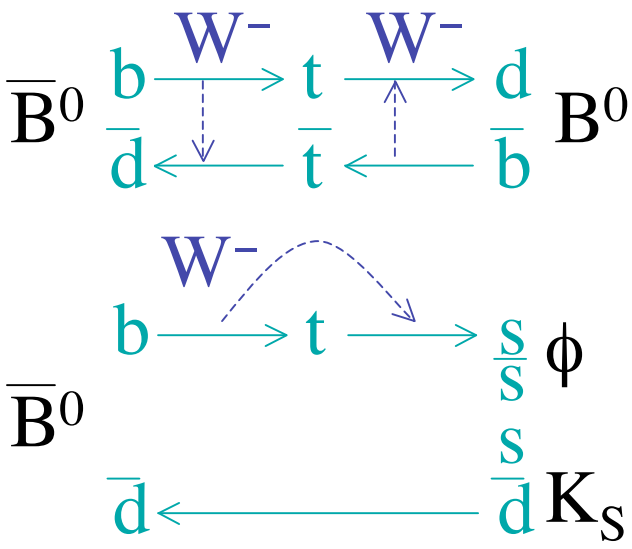
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



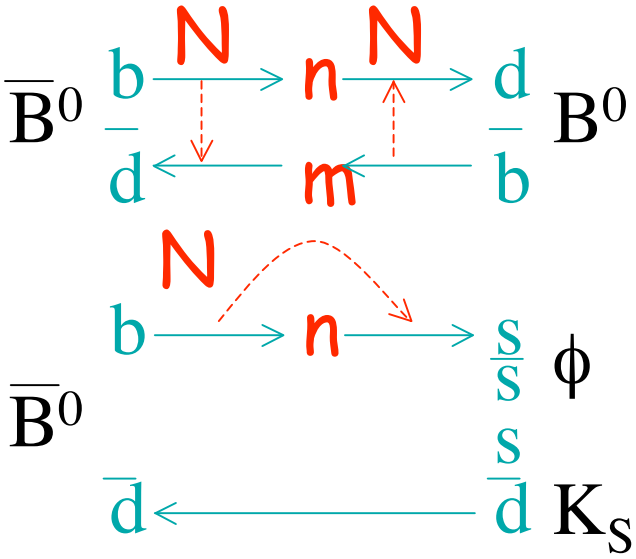


Where could be new physics?

Loop diagrams

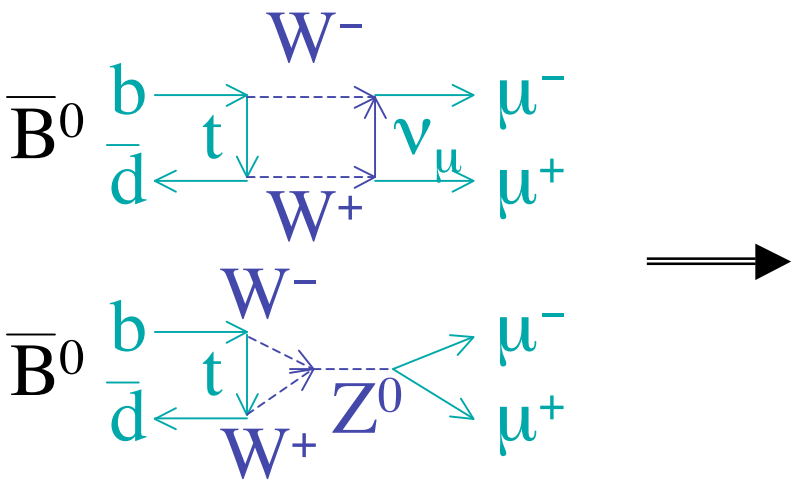


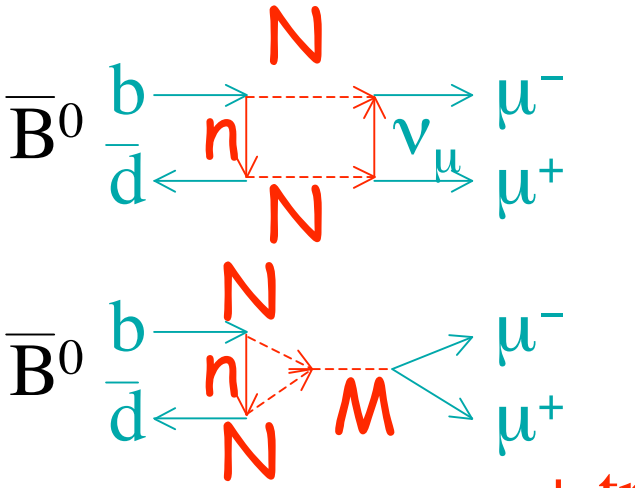
New Particles



B-$\bar{B}$ oscillations

penguin decays



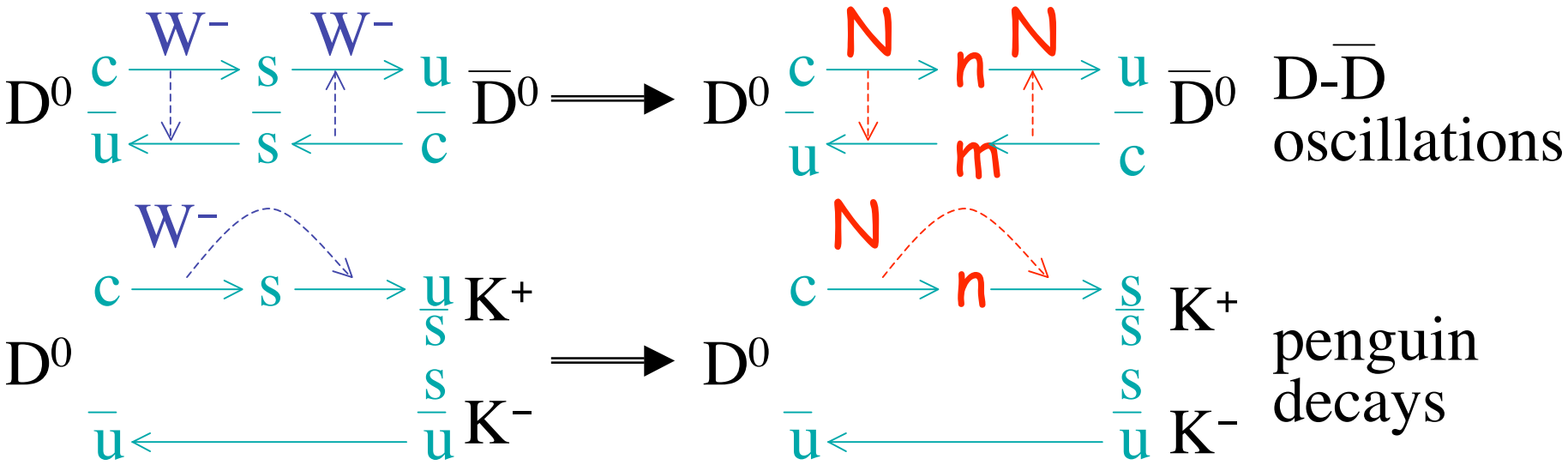


leptonic decays

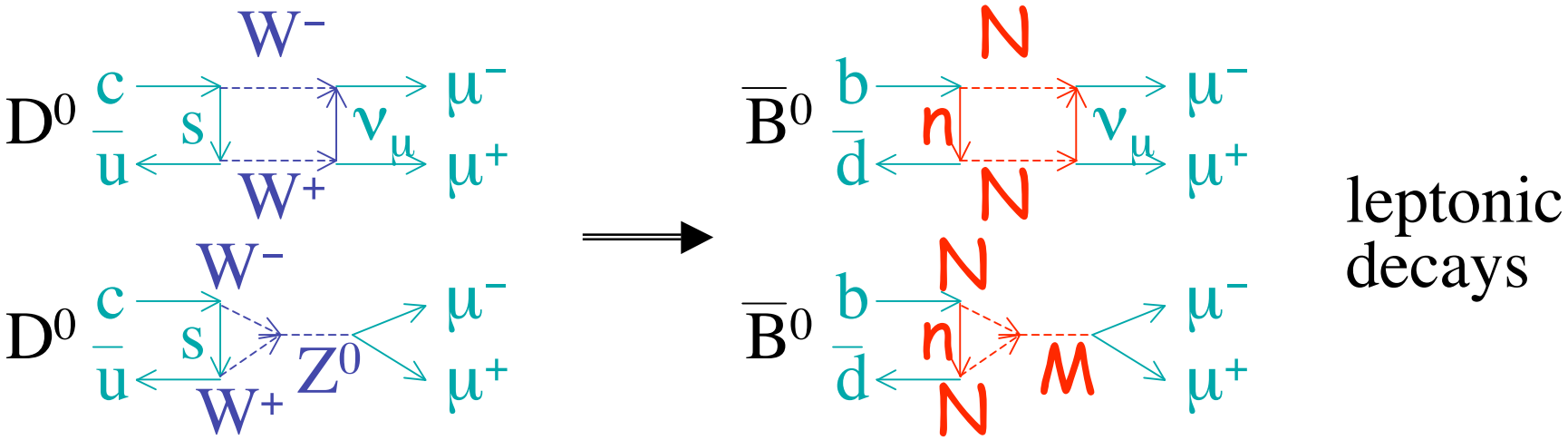
+ tree level

For the D system?

New Particles



NB tree can also make $D^0 \to K^+K^-$



Decay of B and D hadrons are both useful for
improving non-perturbative QCD

lattice, facotization, p-QCD, heavy quark expansion, etc.

lifetimes
branching fractions
sub-system invariant mass distribution
sub-systm strong phase shifts
sub-system poliarisation
etc.

Recent experiments

charm:	FOCUS, E791	(completed)	fix target
	CDF (and D0)		$p\bar{p}$ collider
	LEP experiments	(completed)	e^+e^- at Z^0
	CLEOc		e^+e^- close to $c\bar{c}$-threshold
	BES		
	CLEO	(completed)	e^+e^- at $\Upsilon(4S)$
	BABAR		
	BELLE		
beauty:	CDF (and D0)		$p\bar{p}$ collider
	LEP experiments	(completed)	e^+e^- at Z^0
	CLEO	(completed)	e^+e^- at $\Upsilon(4S)$
	BABAR		
	BELLE		

For b and c production: H1, ZEUS, HERA-B as well

Remark on fix target experiments

Important breakthrough in the middle of 80's:
large number of fully reconstructed D mesons
from the hadronic decays

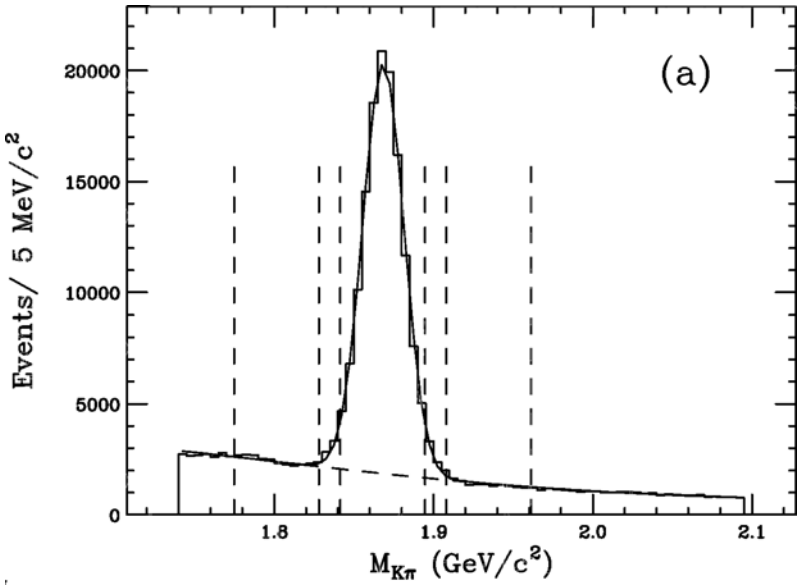
- Si micro-strip vertex detector and open trigger -

$$\frac{\sigma_{c\bar{c}}}{\sigma_{\text{inelastic}}} \approx 10^{-3}$$

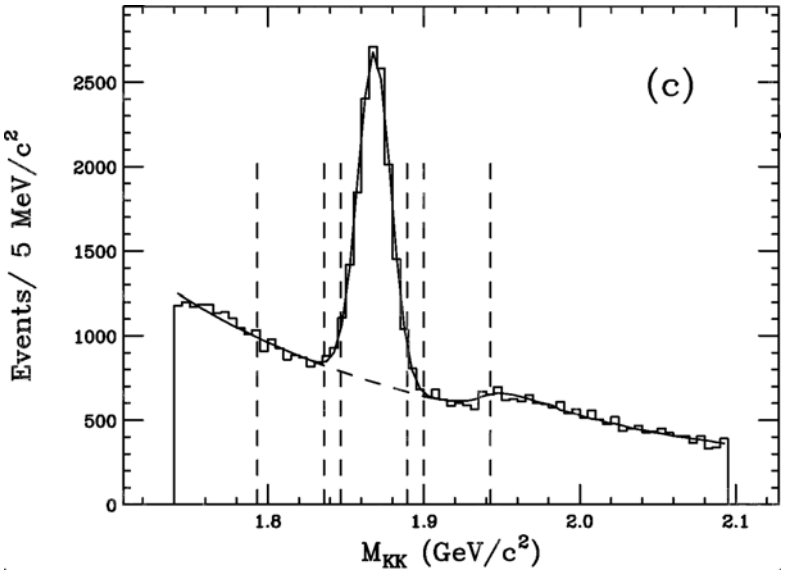
The la(te)st generation of the fix target charm experiments

	beam	statistics	average σ_t
E791	500 GeV π	10^5	40 fs
Focus	up to 300 GeV γ	10^6	30 fs
Selex	600 GeV π, p	10^4	20 fs

Focus

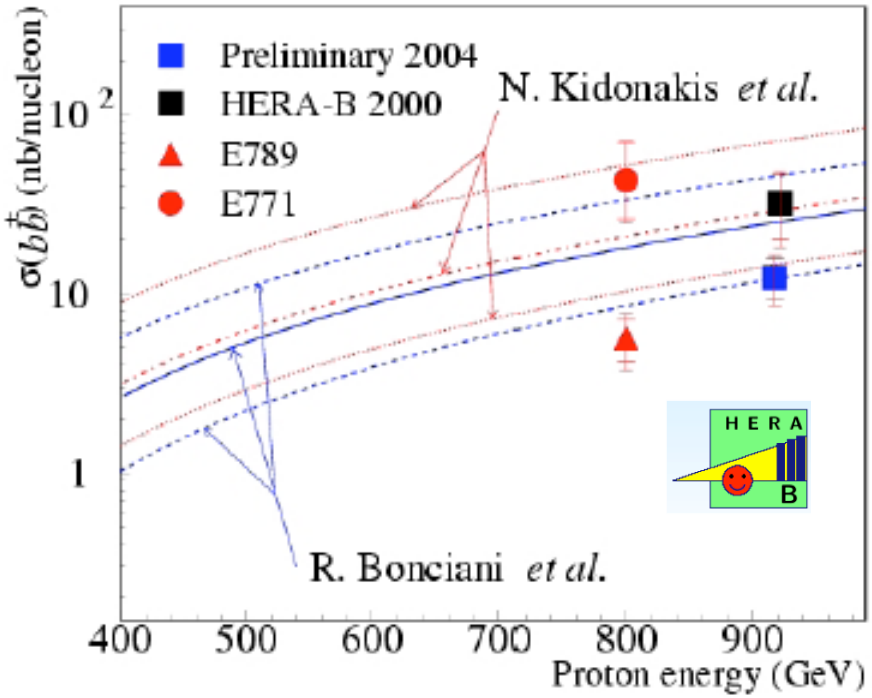


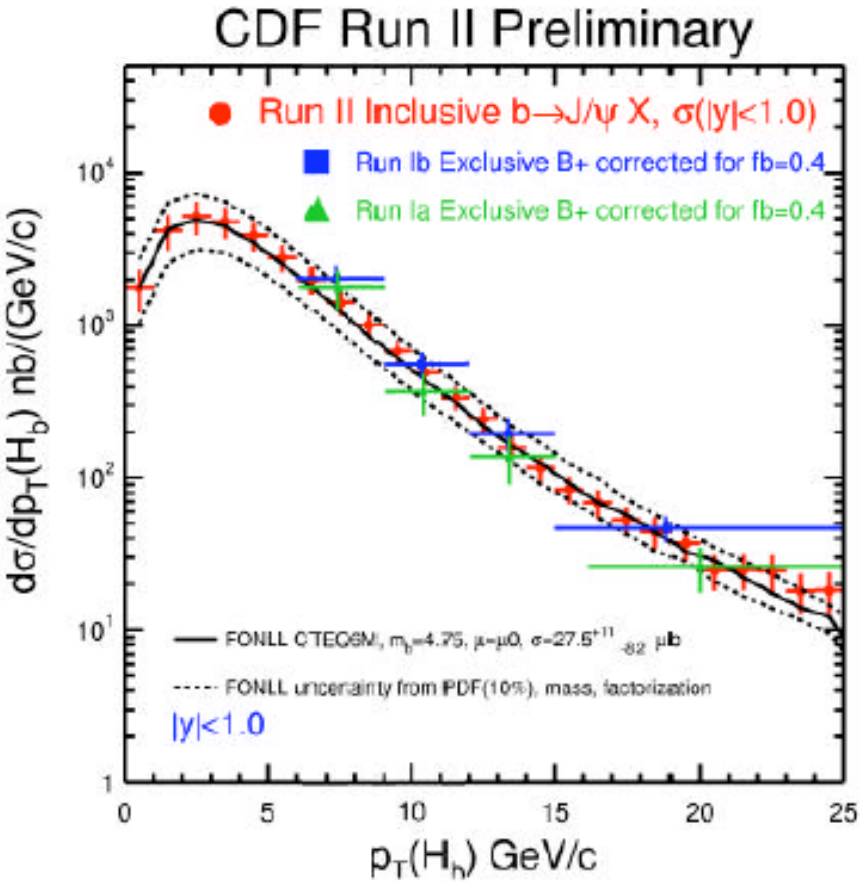
$D^0 \rightarrow K^- \pi^-$ 119738 evts



$D^0 \rightarrow K^+K^-$ 10331 evts

b production





rather good agreement between the data and theory

further progress is expected…

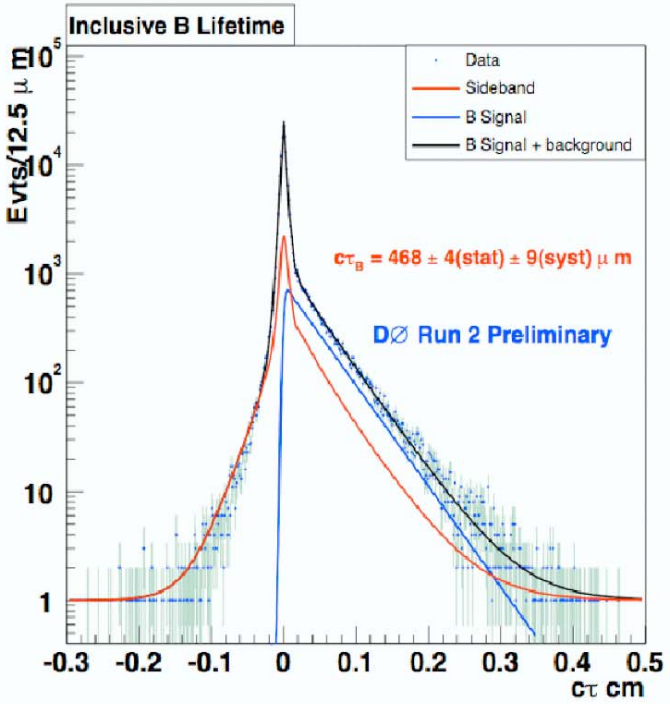
D0

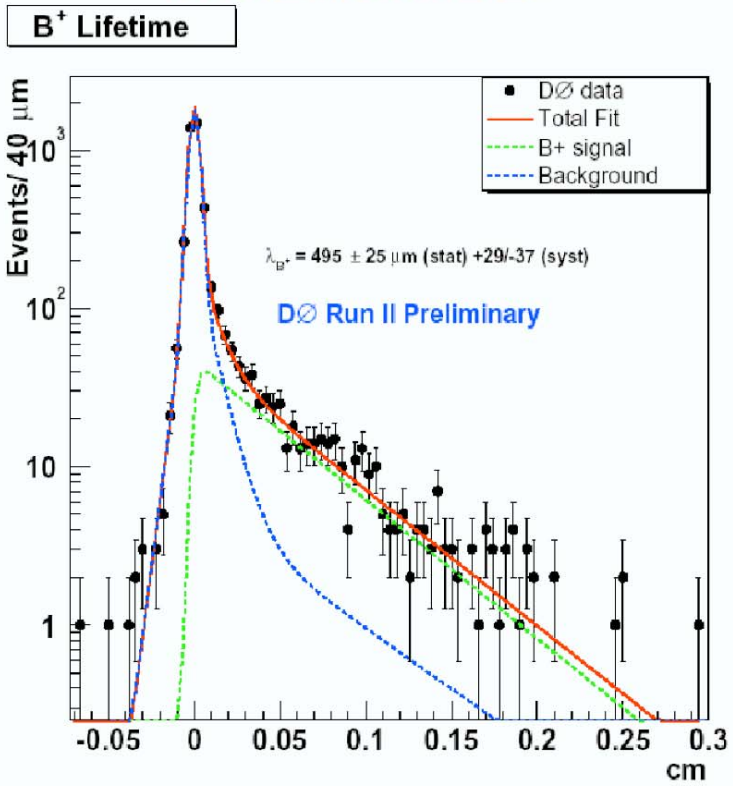
Lifetime Measurements

- Inclusive $B \to J/\psi + X$ lifetime
  - 300k J/ψ's 114 pb^{-1}

1.562 ± 0.013 (stat.) ± 0.045 (sys.) ps

  - 1.564 ± 0.014 (PDG)





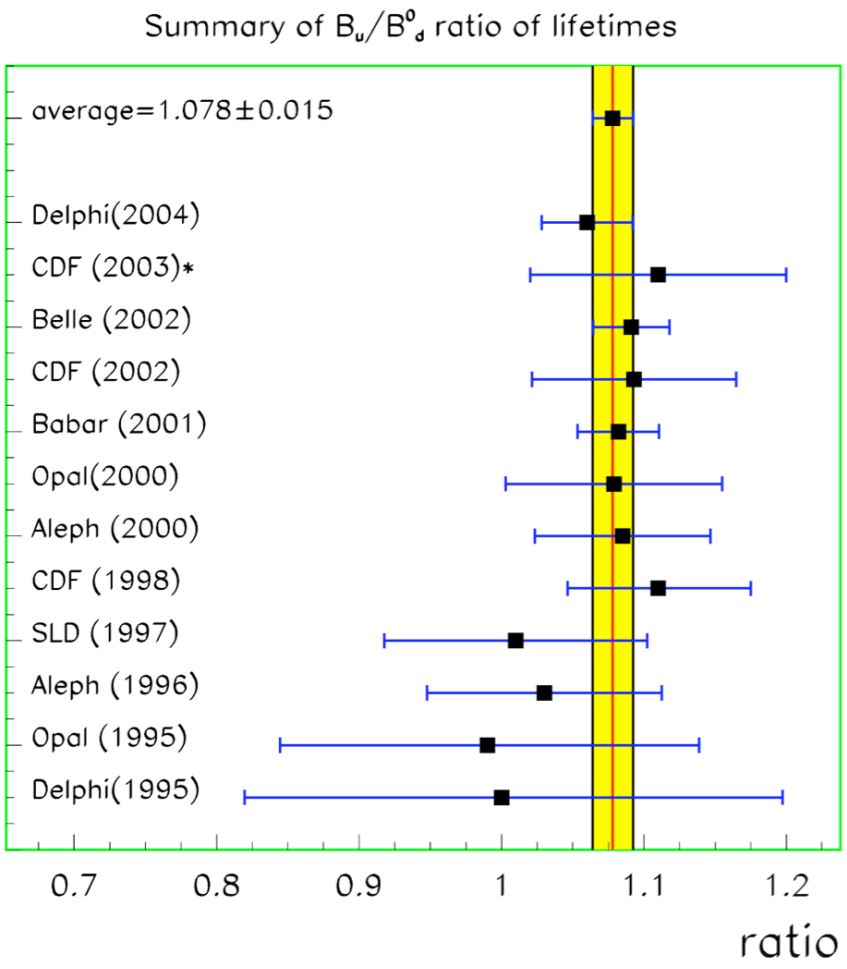
Charged B lifetime, $B^+ \to J/\psi + K^+$

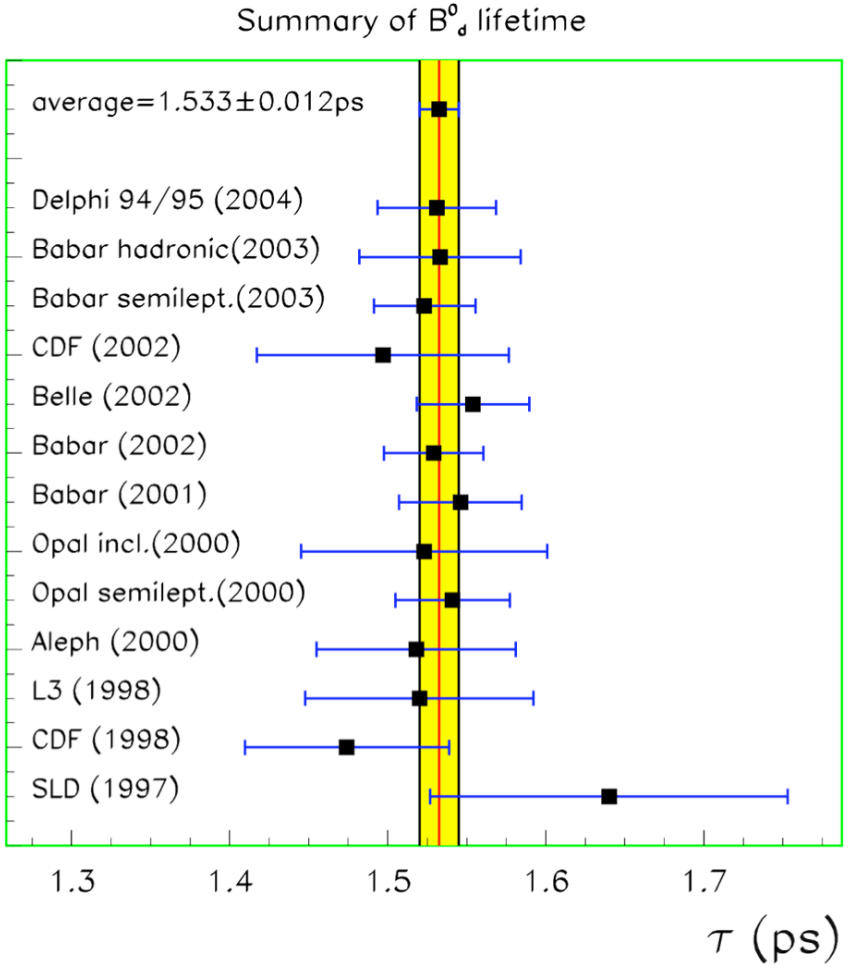
mass: 5.272 ± 0.005 GeV

$$1.65 \pm 0.08(stat.)^{+0.10}_{-0.12}(sys.)\ \text{ps}$$

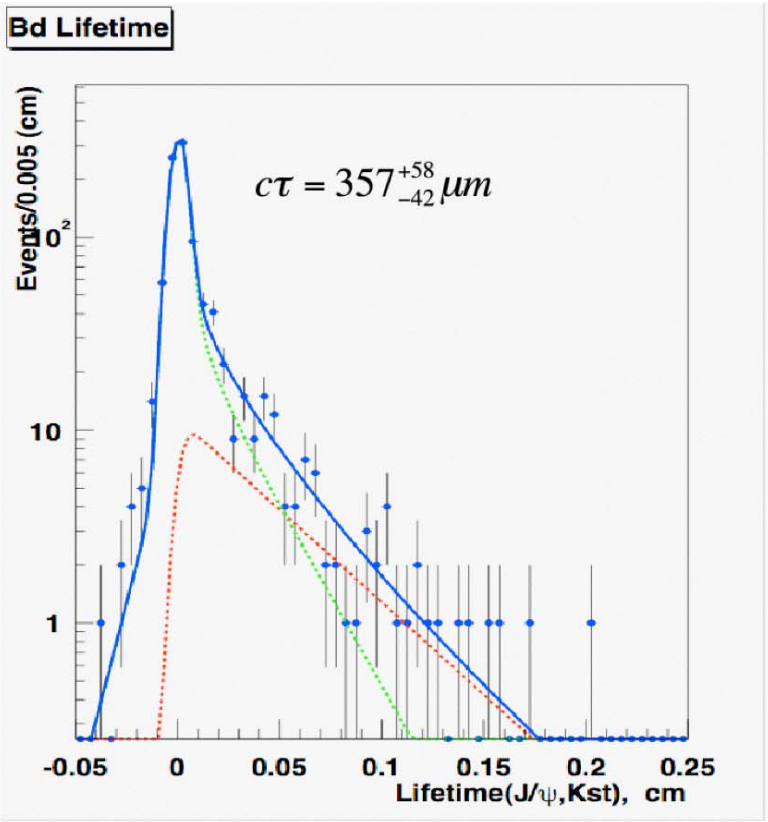
1.671 ± 0.018 ps (PDG)

B lifetimes





BABAR and BELLE
dominate the scene



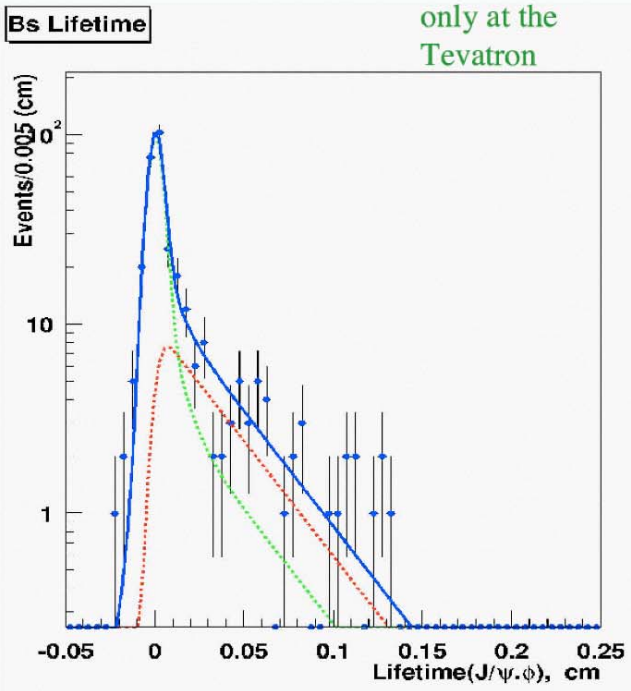
- $B_d \rightarrow J/\psi\, K^*$ **lifetime**
  - 105 ± 19 B_d events
  - $\tau = 1.51^{+0.19}_{-0.17}$ ps

$B_s \rightarrow J/\psi\, \phi$ **lifetime**

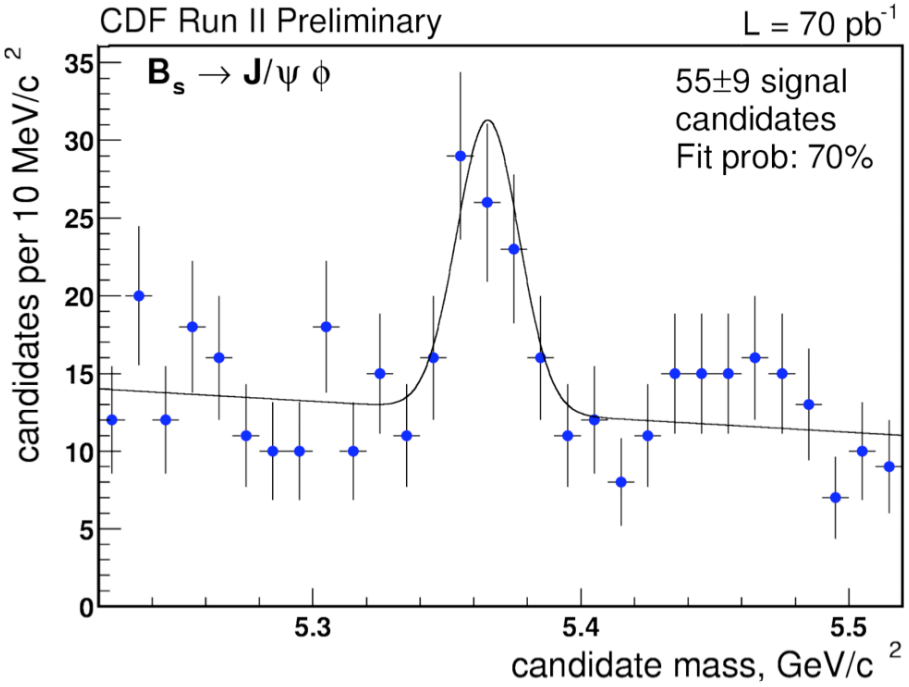
114 pb^{-1}

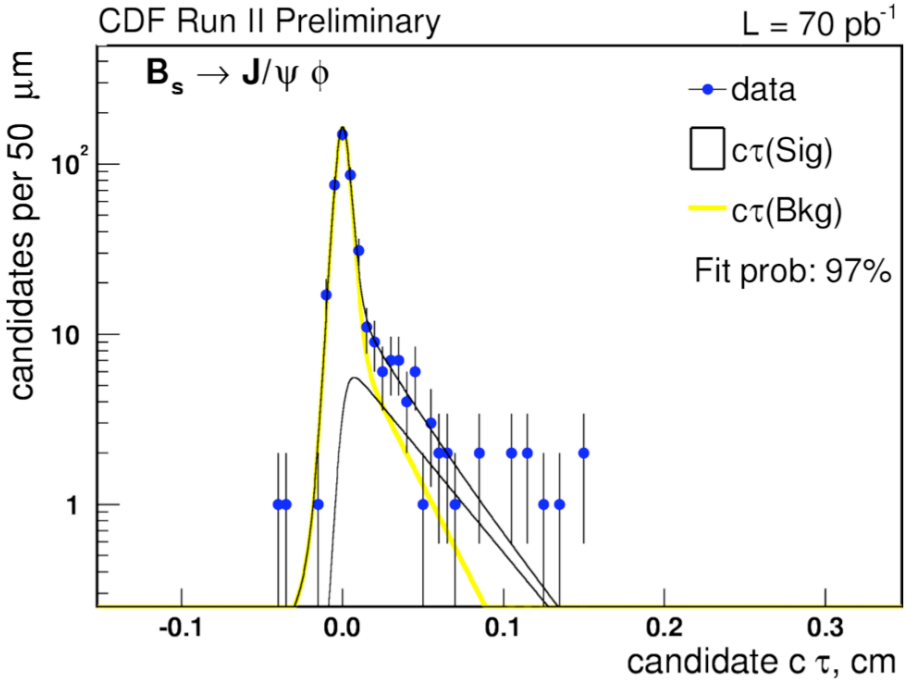
69 ± 14 B_s events

$\tau = 1.19^{+0.19}_{-0.14}$ ps



D0 B_s Run II





$\tau_{B_s} = 1.26 \pm 0.20 \pm 0.02$ ps

CDF B_s Run II

lifetime ratio	HQE expectations	experimental results (using averages)
$\frac{\tau(B_u^+)}{\tau(B_d)}$	1.06 ± 0.02	1.077 ± 0.012
$\frac{\tau(B_s^+)}{\tau(B_d)}$	1.00 ± 0.01	0.926 ± 0.033
$\frac{\tau(\Lambda_b)}{\tau(B_d)}$	0.90 ± 0.05	0.776 ± 0.040

Further improvement from
BABAR/BELLE and CDF/D0 $\longleftarrow$ B_s and Λ_b

charm lifetimes

lifetime ratio	HQE expectations	experimental result (using averages)
$\frac{\tau(D^+)}{\tau(D^0)}$	$\simeq 1 + (\frac{f_D}{200\text{MeV}}) \simeq 2.4$	2.52 ± 0.02
$\frac{\tau(D_s^+)}{\tau(D^0)}$	$1.0 - 1.07$ without WA $0.9 - 1.3$ with WA	1.21 ± 0.01
$\frac{\tau(\Lambda_c^+)}{\tau(D^0)}$	$\simeq 0.5$	0.485 ± 0.007
$\frac{\tau(\Xi_c^+)}{\tau(\Lambda_c^+)}$	$\simeq 1.3 - 1.7$	2.2 ± 0.1
$\frac{\tau(\Lambda_c^+)}{\tau(\Xi_c^0)}$	$\simeq 1.6 - 2.2$	1.80 ± 0.18
$\frac{\tau(\Xi_c^+)}{\tau(\Xi_c^0)}$	$\simeq 2.8$	4.0 ± 0.4
$\frac{\tau(\Xi_c^+)}{\tau(\Omega_c^0)}$	$\simeq 4$	5.39 ± 1.05
$\frac{\tau(\Xi_c^0)}{\tau(\Omega_c^0)}$	$\simeq 1.4$	1.5 ± 0.32

BABAR/BELLE will improve the results

CKM physics now

Tree level measurements

$|V_{ud}|, |V_{us}|, |V_{ub}|, |V_{cd}|, |V_{cs}|, |V_{cb}|$

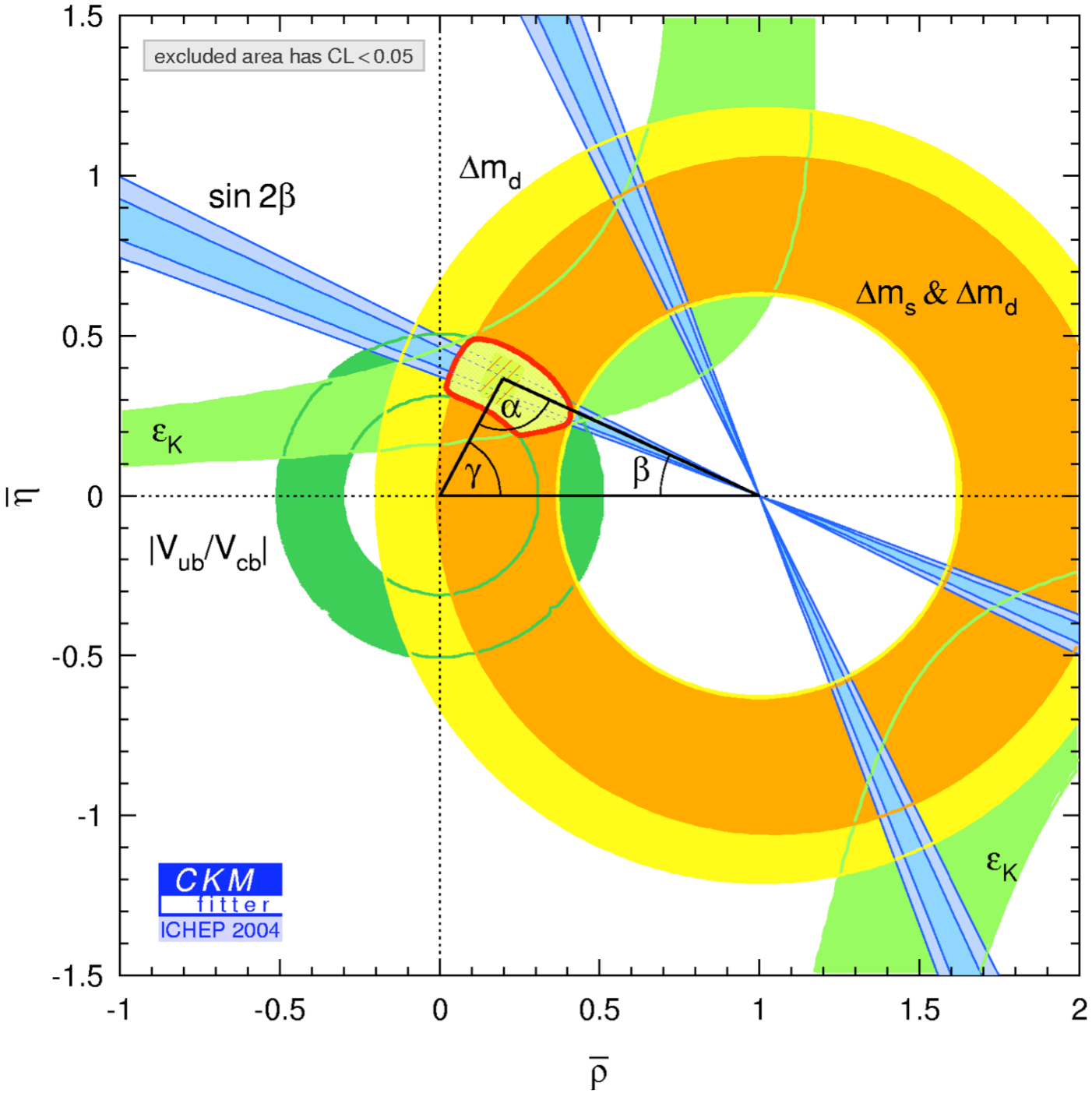
+ loop level measurements

$|V_{td}|$, limit on $|V_{ts}|$

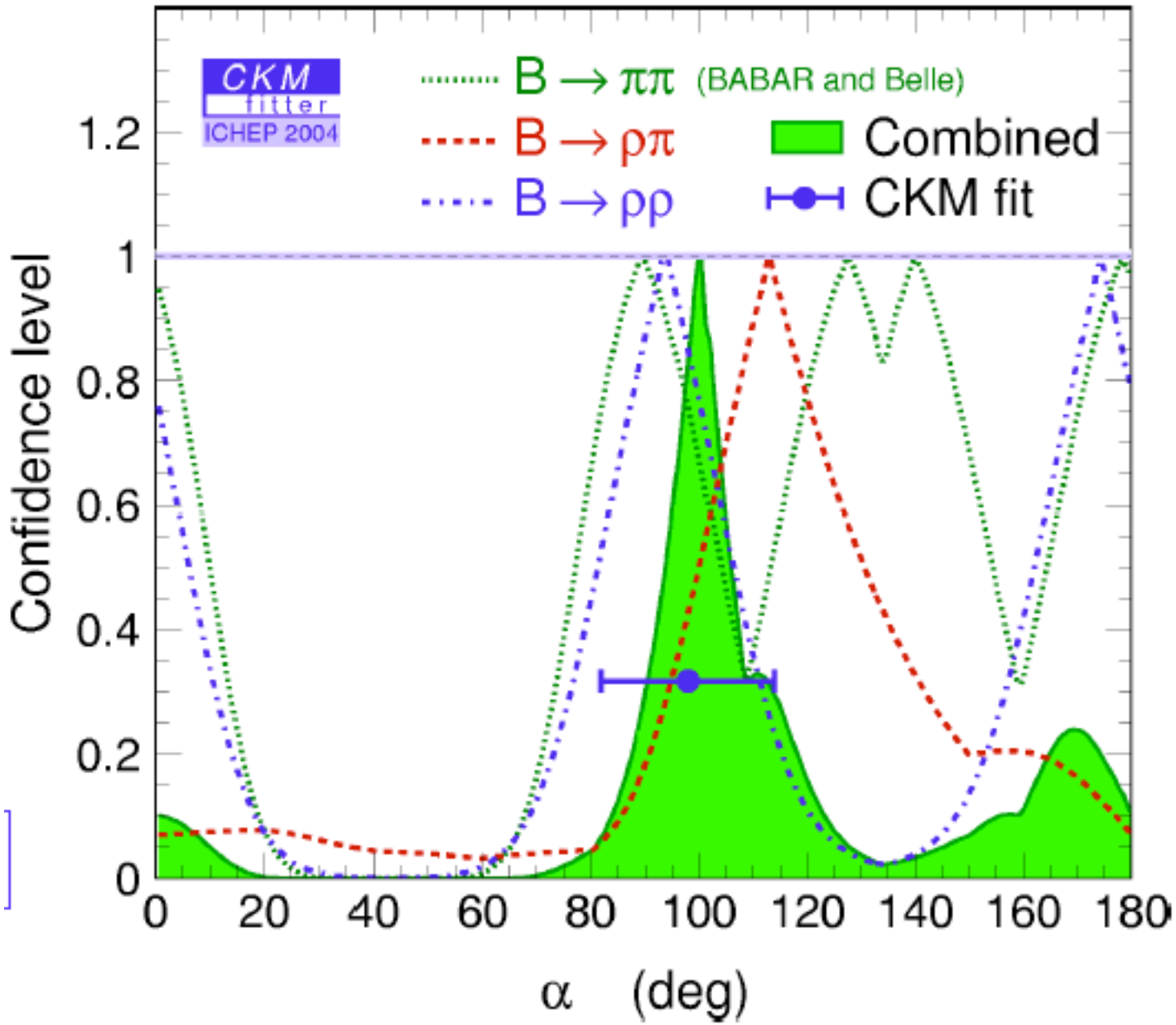
CP violation measurments:

ε(K), $\sin 2\beta(b \to c\bar{c}s)$

are compatible with the CKM picture


excluded area has CL < 0.05
sin 2β
Δm_d
Δm_s & Δm_d
ε_K
|V_ub/V_cb|
α
β
γ
CKM fitter
ICHEP 2004
1.5
1
0.5
0
-0.5
-1
-1.5
-1
-0.5
0
0.5
1
1.5
2
η̄
ρ̄

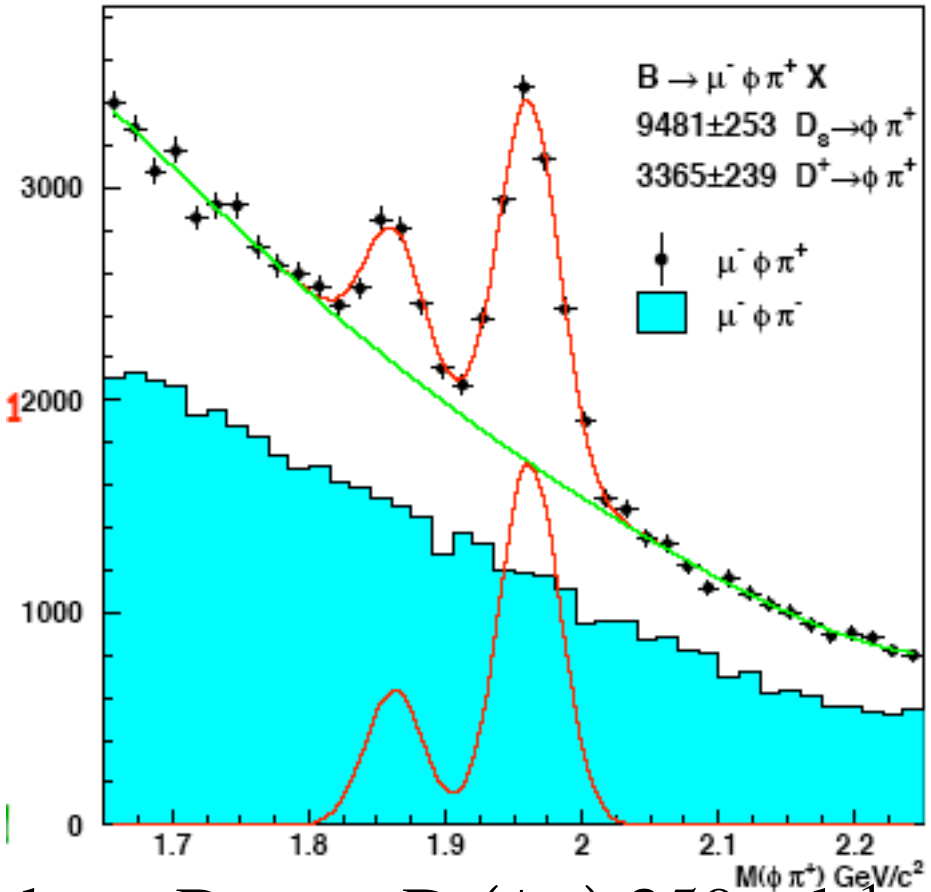
Also some other measurements are compatible…



B_s oscillations

CDF+D0 1 fb^{-1} total by the end of 2004?

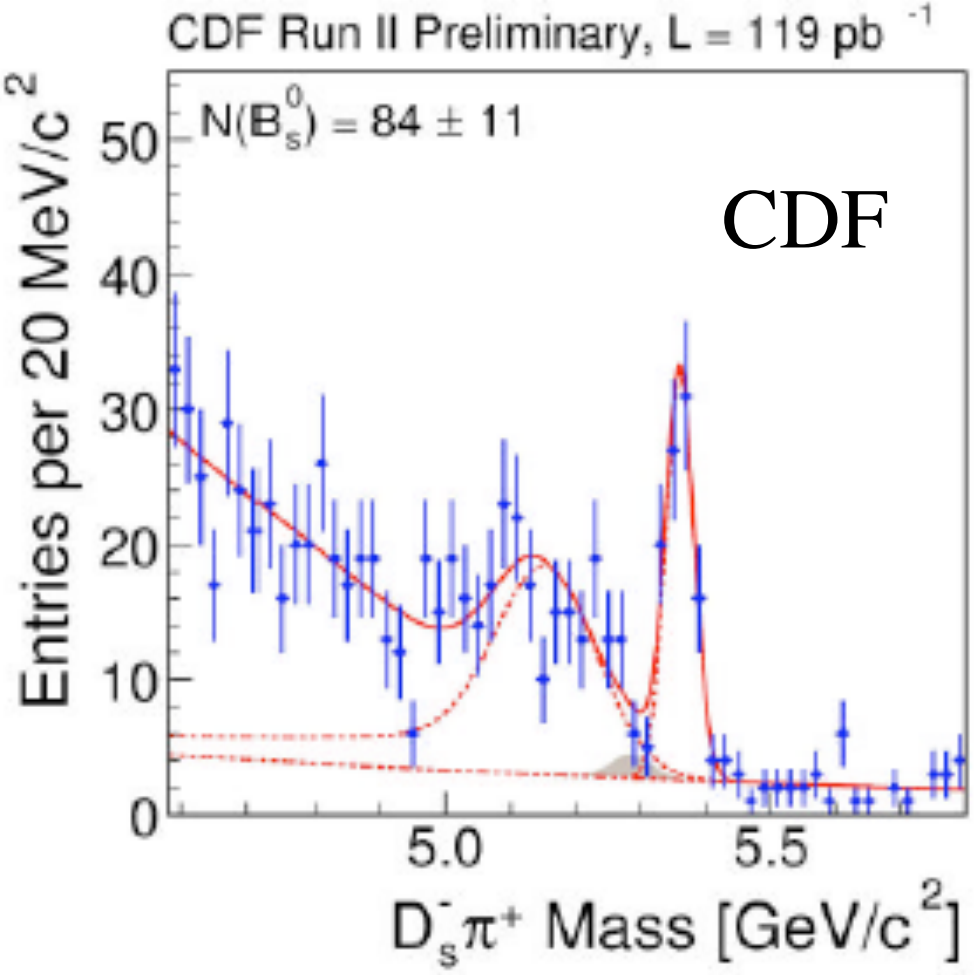
D0



9.5K candidates $B_s \rightarrow \mu\nu D_s(\phi\pi)$ 250 pd^{-1}

with 500 pd^{-1} up to Δm_s=15 ps^{-1}

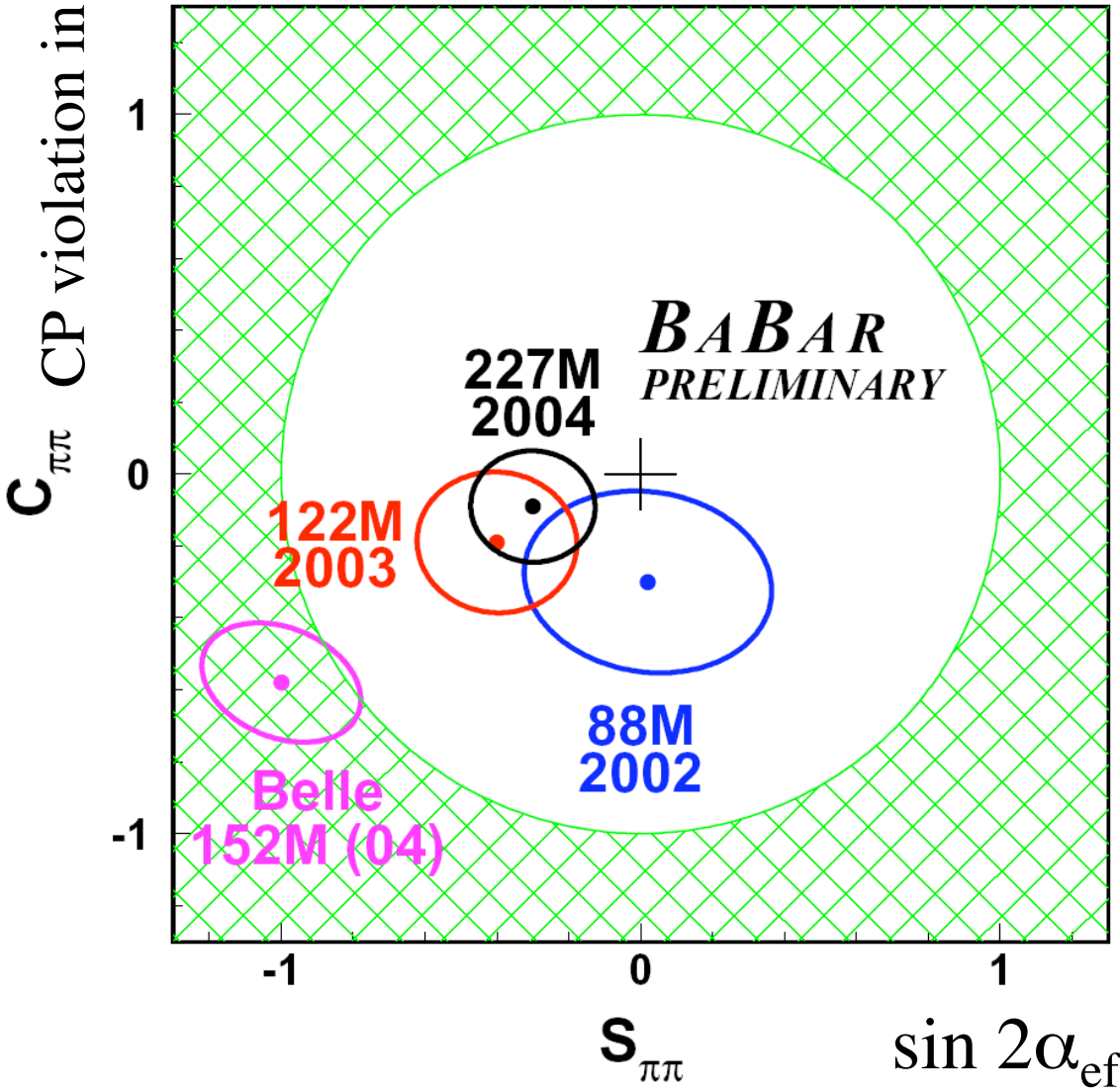
large sample but limited *t* resolution due to
missing particle
large background $D_s \rightarrow D_s\pi$ decays



final reach $\Delta m_s \approx 20\ ps^{-1}$

Are there any problems? Yes there are…

$B \to \pi^+\pi^-$ decays



BABAR and BELLE are not completely compatible.

BELLE result is not really compatible with CKM prediction

More data needed!

NB: theoretical uncertainty is not small.

CP asymmetry ($J/\psi\ K_S$) $\propto$ arg(B-$\bar{B}$) + arg($2V_{cb}V_{cs}^*$)

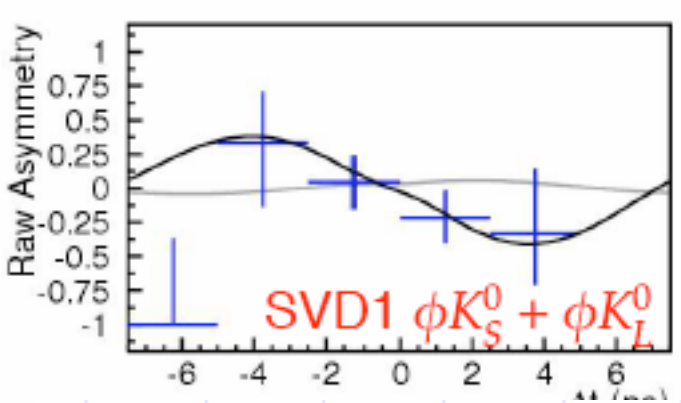
CP asymmetry ($\phi\ K_S$) $\propto$ arg(B-$\bar{B}$) + arg($2V_{ts}V_{tb}^*$)

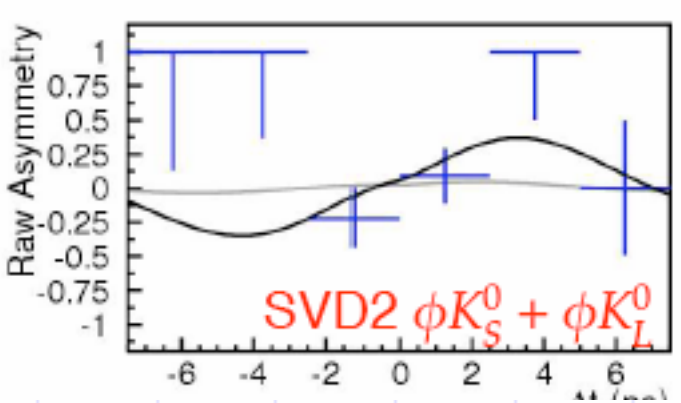
In the SM, arg(B-$\bar{B}$) = 2β

$0 = \arg(V_{cb}V_{cs}^*) \approx \arg(V_{ts}V_{tb}^*)$

CP asymmetry ($J/\psi\ K_S$) = CP asymmetry ($\phi\ K_S$)

BELLE (somewhat confusing)





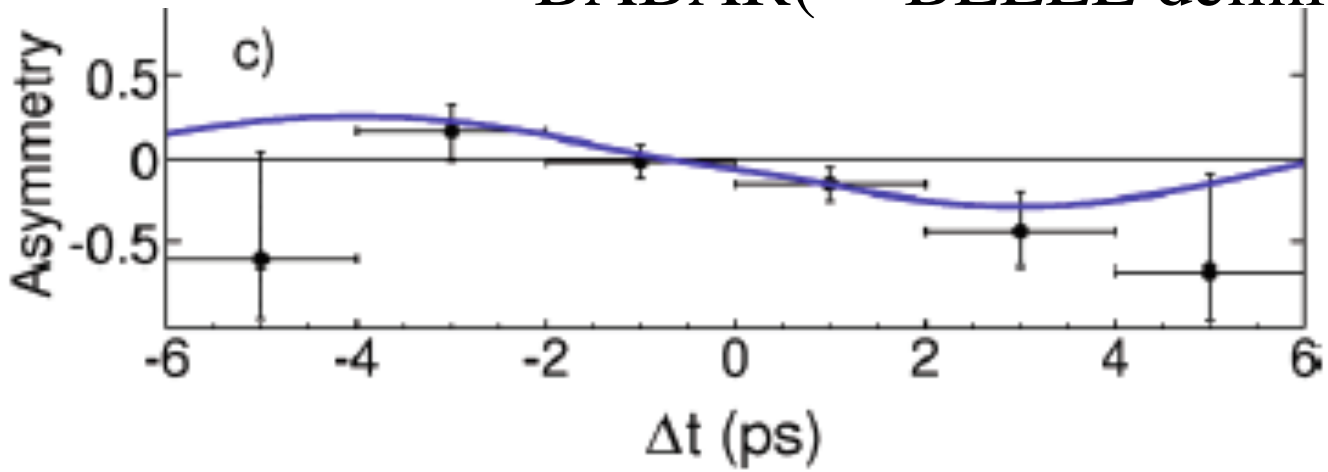
SVD1 only

"$\sin 2\phi_1$" $= -0.68 \pm 0.46$

SVD2 only

"$\sin 2\phi_1$" $= +0.78 \pm 0.45$

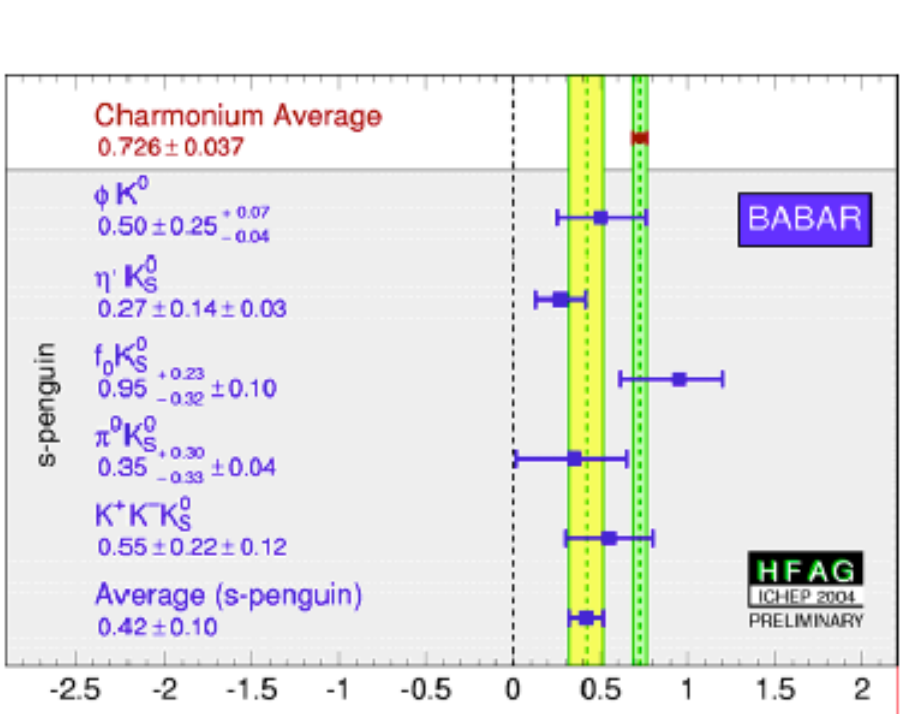
BABAR(=−BELLE definition)

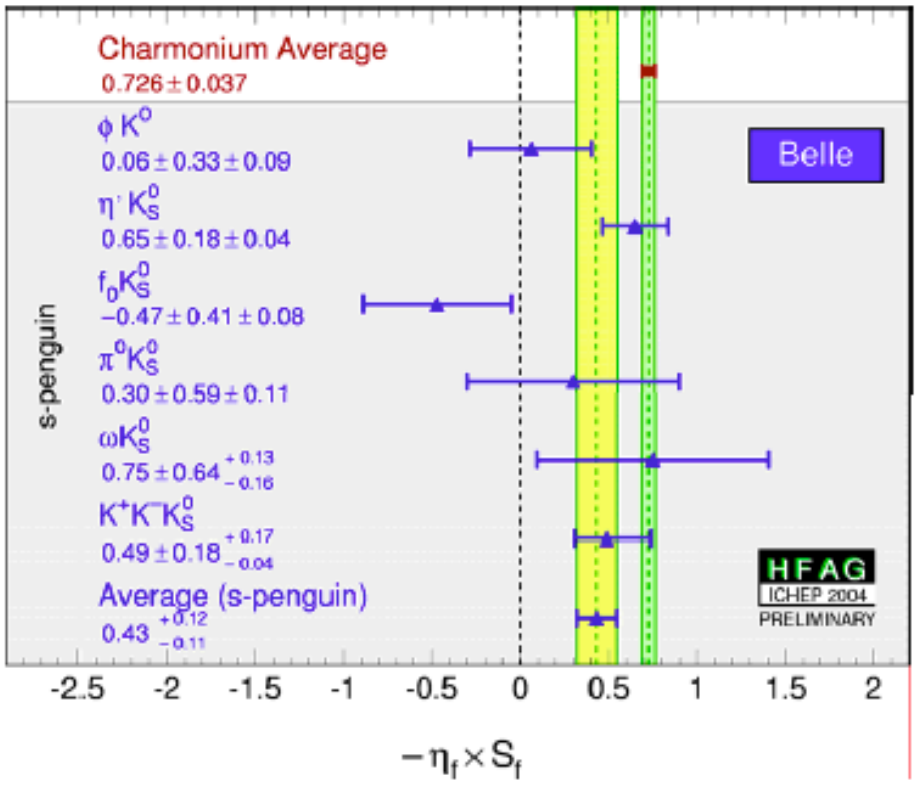


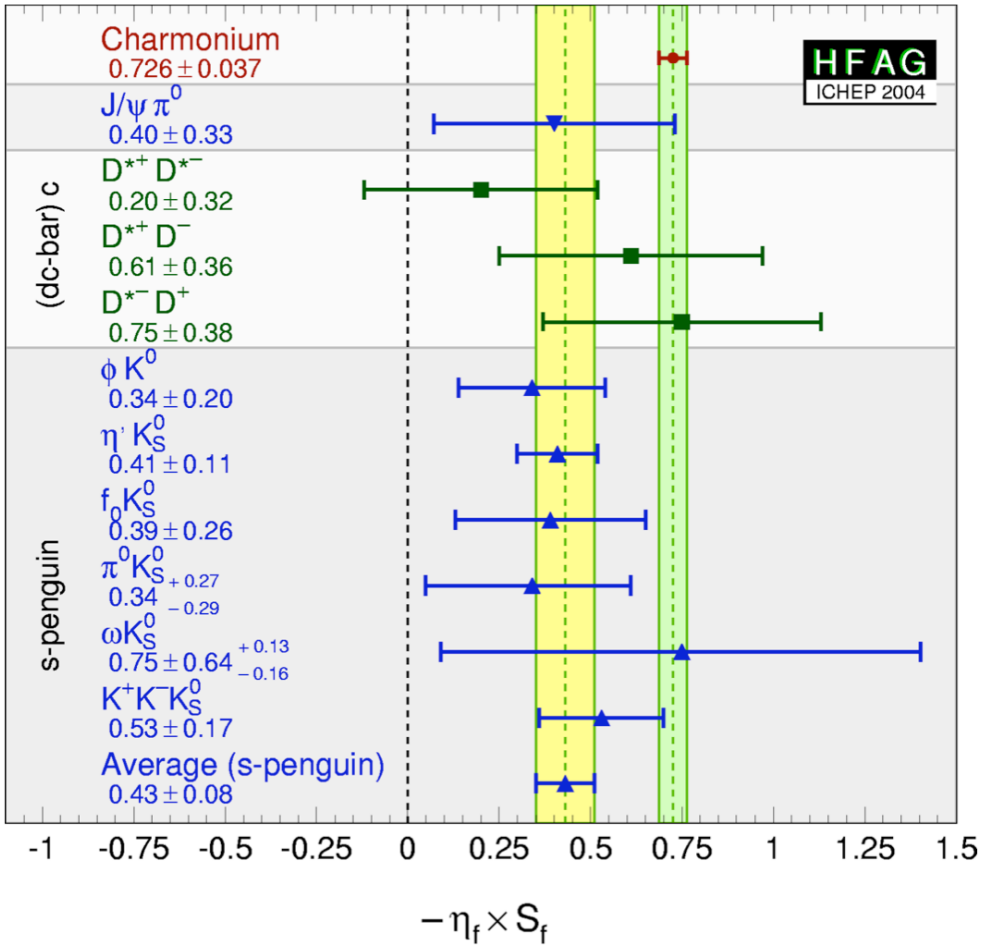
sin 2β measured from

b→c$\bar{c}$s (charmonimum)

b → ss$\bar{s}$ (s penguin)







3.6σ from s-penguin to sin2β ($c\bar{c}$)

sign of new physics?

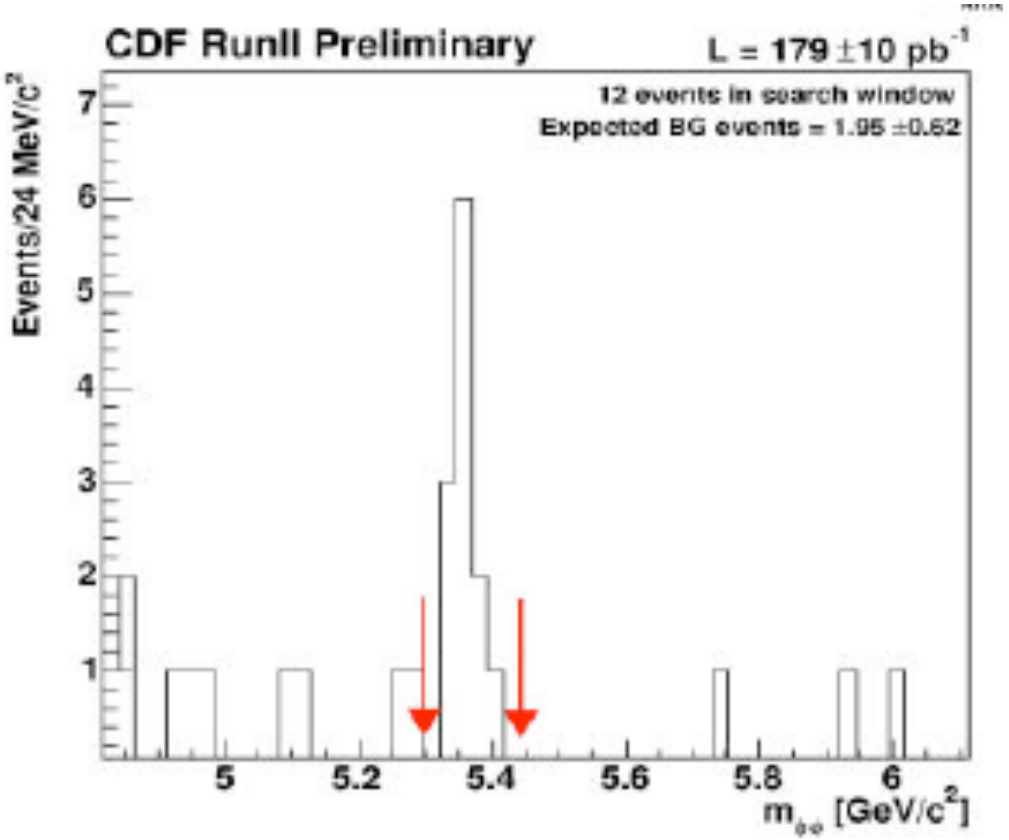
We need

more data→BABAR and BELLE

study with the B_s system

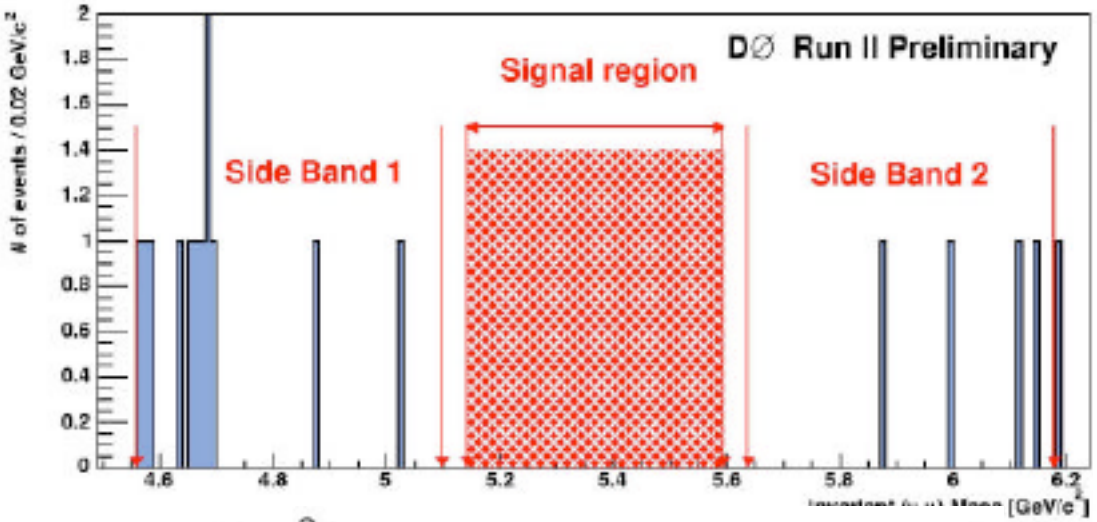
CP asymmetry in J/ψ φ and φφ→LHCb and BTeV

$B_s \rightarrow \phi\phi$ has been seen by CDF



Br = (1.4 ± 0.6 ± 0.2 ± 0.5)×10–5

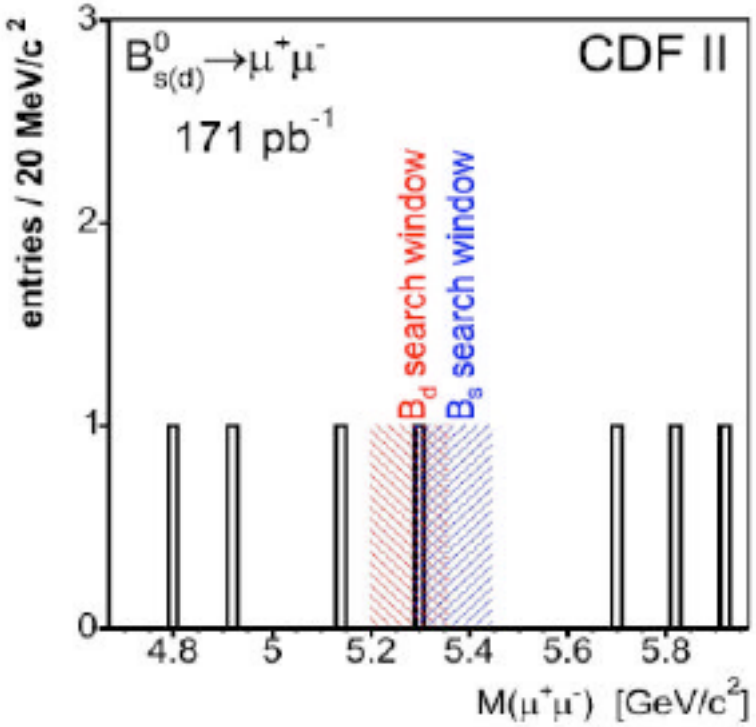
B→μμ



$BR(B_s \rightarrow \mu^+ \mu^-) < 5.8 \times 10^{-7}$

$BR(B_d \rightarrow \mu^+ \mu^-) < 1.5 \times 10^{-7}$

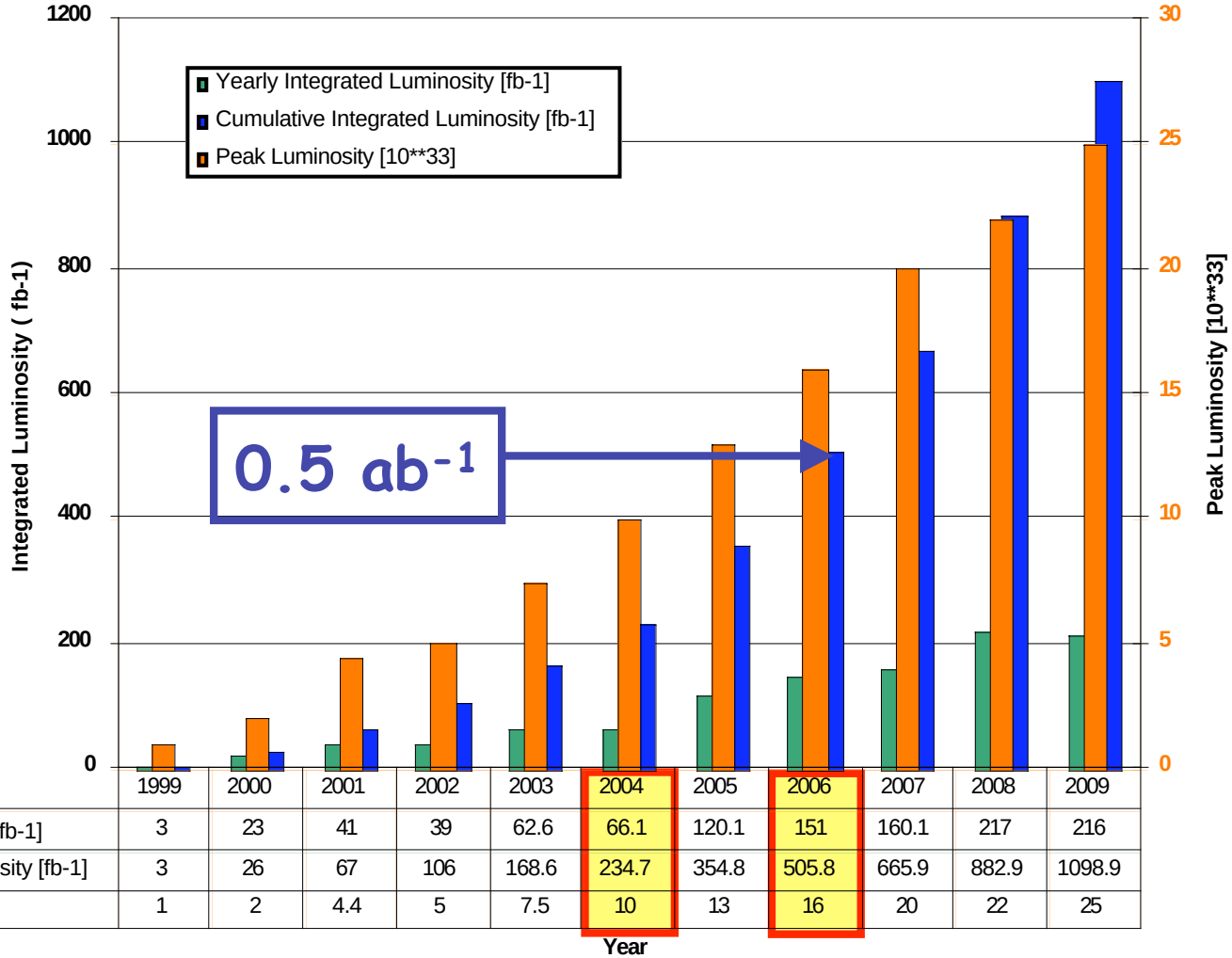
90% CL



SM = 10^{-10}~10^{-9}

LHC experiments and BTeV will reach this sensitivity

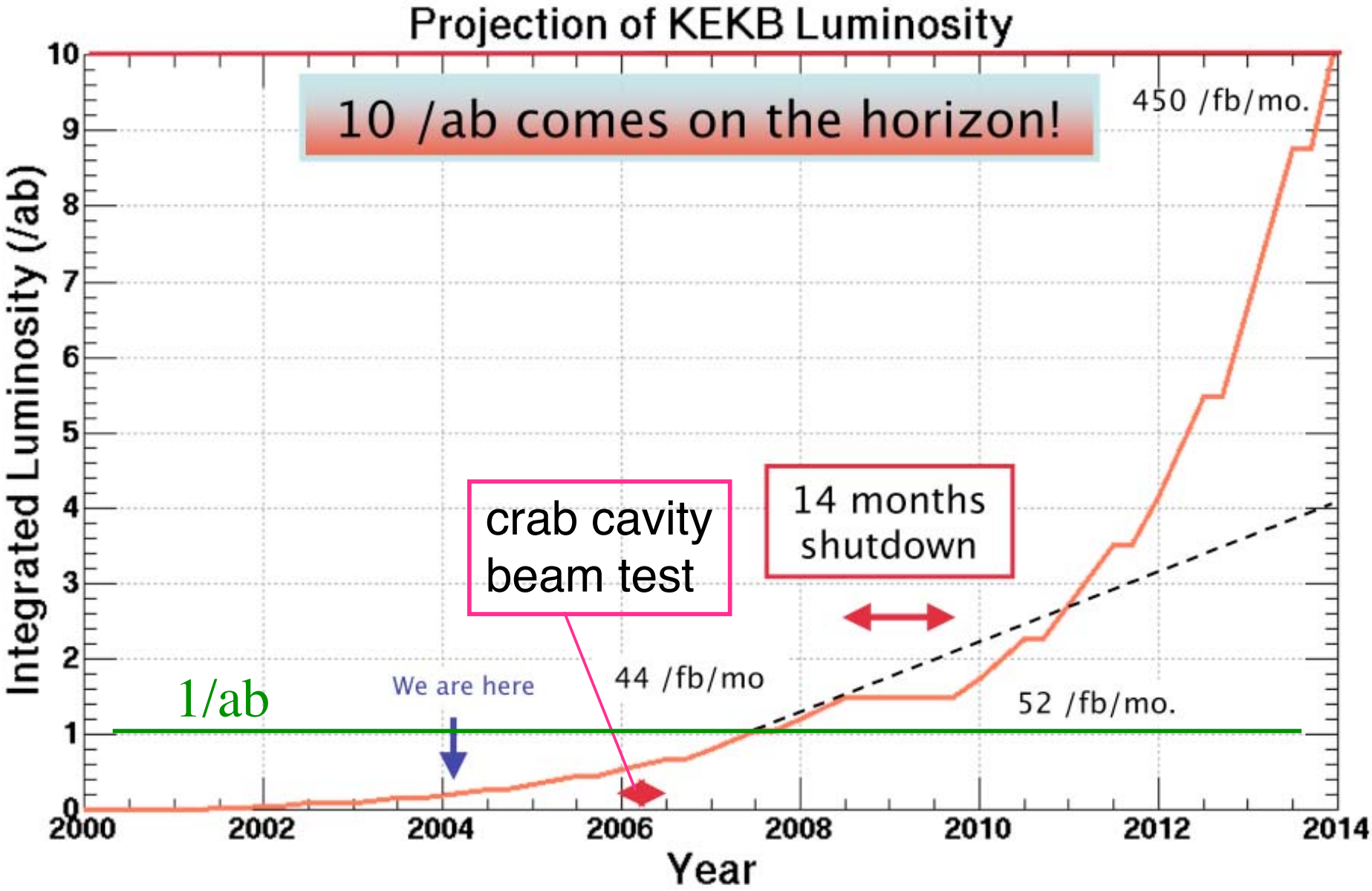
PEP-II projection



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Yearly Integrated Luminosity [fb-1]	3	23	41	39	62.6	66.1	120.1	151	160.1	217	216
Cumulative Integrated Luminosity [fb-1]	3	26	67	106	168.6	234.7	354.8	505.8	665.9	882.9	1098.9
Peak Luminosity [10**33]	1	2	4.4	5	7.5	10	13	16	20	22	25

2004 2006

1.6×10^{34}


Projection of KEKB Luminosity
10 /ab comes on the horizon!
450 /fb/mo.
Integrated Luminosity (/ab)
crab cavity
beam test
14 months
shutdown
1/ab
We are here
44 /fb/mo
52 /fb/mo.
Year
0
1
2
3
4
5
6
7
8
9
10
2000
2002
2004
2006
2008
2010
2012
2014

B factory statistics

- Now (ICHEP04):
  - BABAR+ Belle have analyzed 227 M + 274 M ~ 500 M BB pairs
- BABAR plans:
  - take data until end of 2008, with increasing luminosity, then 2-year shutdown
  - peak luminosity ($cm^{-2}s^{-1}$): $L_{peak} = 0.9\times10^{34}$ (now) → 2–3 $\times10^{34}$ (2007)
  - current goal is 500 fb^{-1} at the end of 2006 (BAD #828, Aug 2004)
  - assume ~ 1000 fb^{-1} by the end of 2008
- Belle plans:
  - two more years at $L\sim1.5\times10^{34}$ (with crab-crossing tests early 2006)
  - followed by two years at $L\sim2\times10^{34}$, before 1-year shutdown (summer 2008 ?)
  - safely expect ~ 1000 fb^{-1} (optimistically 1500 fb^{-1}) by the end of 2008
- Expected total statistics at end of B-factory era (i.e. before super-B):
  - 2000–2500 fb^{-1} ⇔ 2200–2700 M inclusive BB pairs
  - effective tagging efficiency: $\varepsilon D^2 = 30\%$

~1.5K perfectly tagged $B\to\pi^+\pi^-$

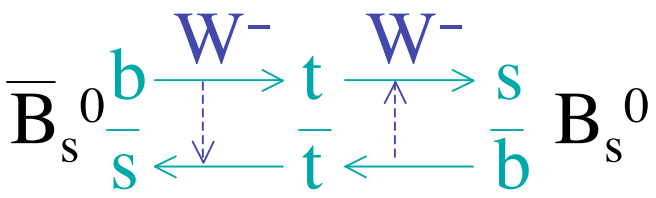
LHCb 4K perfectly tagged $B\to\pi^+\pi^-$ in one year

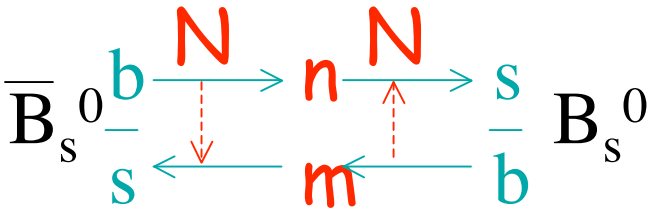
Special to LHCb (and BTeV)

- large sample of B_d and B_s allow to measure γ with theoretically clean decay modes.
- γ can be measured from different decay modes which would be affected differently be the new physics.

$B_s \rightarrow J/\psi\ \phi,\ J/\phi\ \eta$	box phase
$D_s\ K$	$b\rightarrow u$ + $b\rightarrow c$ trees phase
K^+K^-	$b\rightarrow u$ tree + $b\rightarrow s$ penguin phase
$K^{\pm}\ \pi^{\mp}$	$b\rightarrow u$ tree + $b\rightarrow d$ penguin phase
$\phi\ \gamma$	$b\rightarrow s$ penguin (electromagnetic)
$\phi\ \mu^+\mu^-$	$b\rightarrow s$ penguin+box (electroweak)
$K^{*0}\ \gamma$	$b\rightarrow d$ penguin (electromagnetic)
$K^{*0}\ \mu^+\mu^-$	$b\rightarrow d$ penguin+box (electroweak)
$\phi\ \phi$	$b\rightarrow s$ penguin
$\phi\ K_S$	$b\rightarrow d$ penguin
$\phi\ K^{*0}$	$b\rightarrow d$ penguin
$\mu^+\mu^-$	box

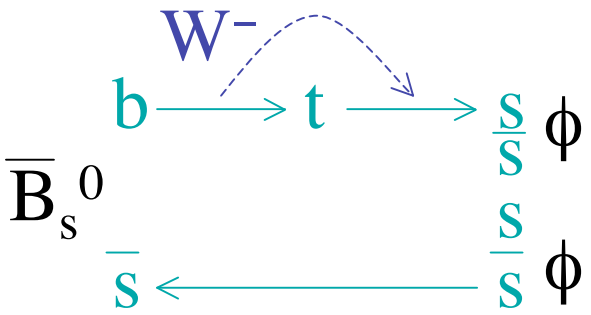
And equivalent B_d decays

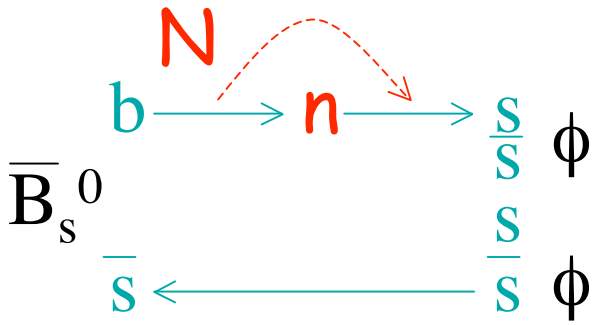




$$CP(J/\psi\phi) \rightarrow 2\chi + \Phi_{NP}$$

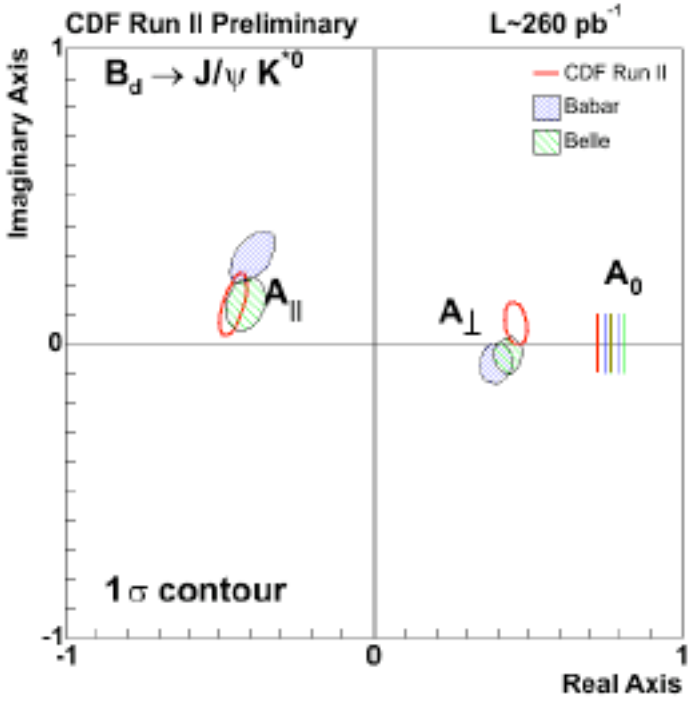
$$CP(D_SK) \rightarrow 2\chi + \gamma + \Phi_{NP}$$

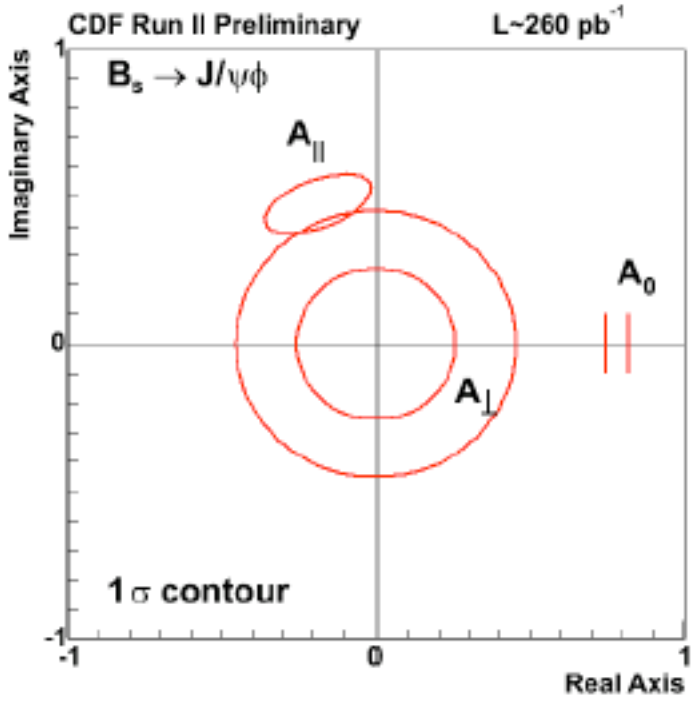




$$CP(\phi\phi) \rightarrow 2\chi + \Phi_{NP} + \Phi_{NP}^{decay}$$

Similar to $J/\psi K_S$, $J/\psi\phi$ needs angular analysys
CDF shows that this is possible!





A_0 and $A_{pararell}$ CP even

$A_{parpendicular}$ CP odd

$B_s \to D_s K$ and $B_s \to J/\psi\, \phi$

After one year, if $\Delta m_s = 20\ ps^{-1}$, $\Delta\Gamma_s/\Gamma_s = 0.1$, $55 < \gamma < 105$ deg, $-20 < \Delta_{T1/T2} < 20$ deg:

$\sigma(\gamma) = 14$–15 deg

- No theoretical uncertainty
- No effect from new physics
- $|A(b\to u)_{tree}/A(b\to c)_{tree}|$ fitted from the asymmetry (advantage over $B^0 \to D^*\pi$)

$B_s \to K^+K^-$, $B_d \to \pi^+\pi^-$
$B^0 \to J/\psi\ ks$ and $B_s \to J/\psi\, \phi$

If $\Delta m_s = 20\ ps^{-1}$, $\Delta\Gamma_s/\Gamma_s = 0.1$, $d = 0.3$, $\vartheta = 160$ deg, $55 < \gamma < 105$ deg:

$\sigma(\gamma) = 4$–6 deg

- U-spin symmetry assumed
- New physics in b→s and b→s penguins affect the measurement

$B^0 \to D^0K^{*0}$, $B^0 \to D^0K^{*0}$, $B^0 \to D_{CP}K^{*0}$ + c.c.

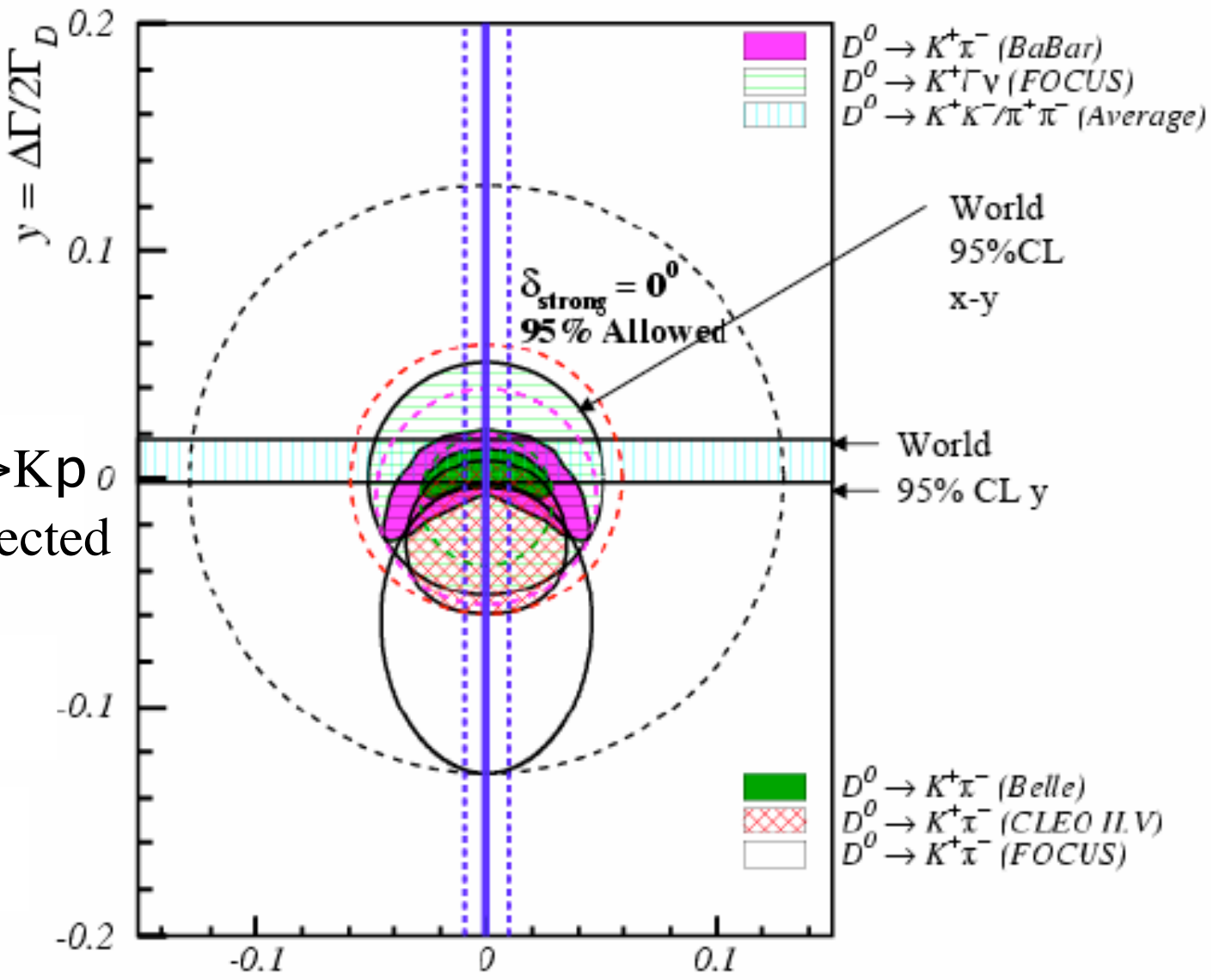
$\sigma(\gamma) = 7$–8 deg

$55 < \gamma < 105$ deg
$-20 < \Delta < 20$ deg

- No theoretical uncertainty
- New physics in the D-$\bar{D}$ box diagrams affects the measurement

D-$\overline{D}$ mixing

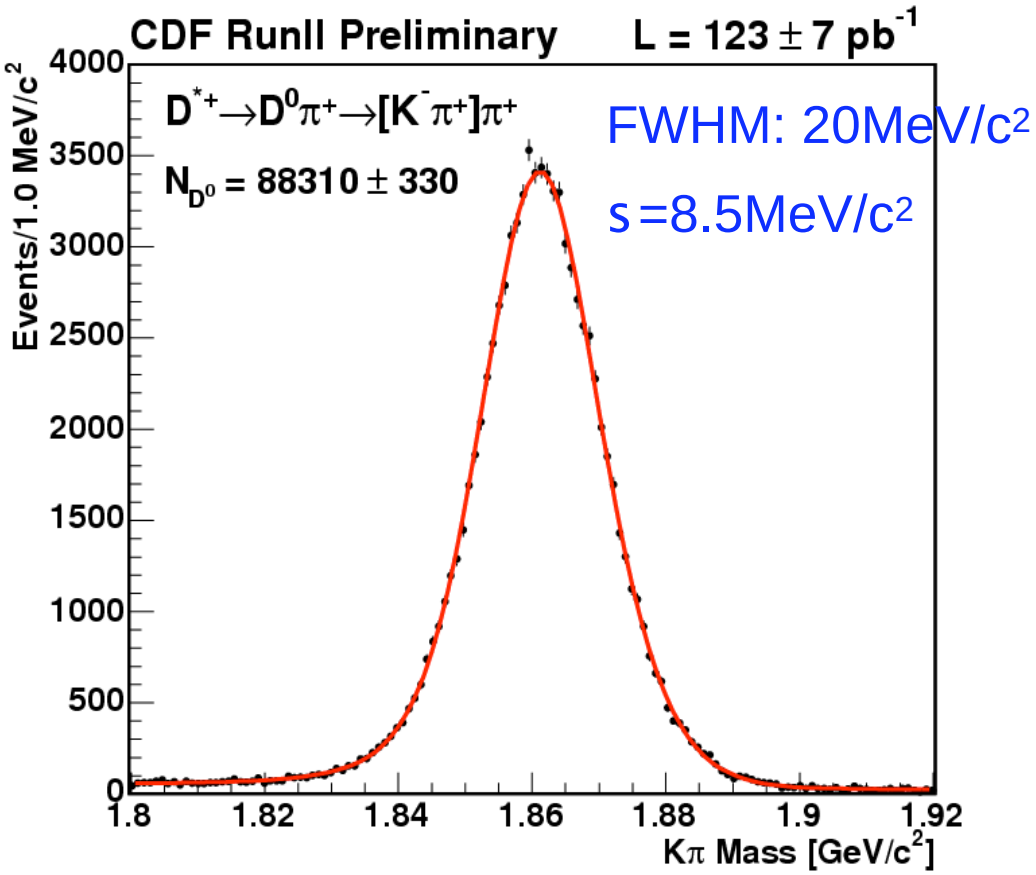
CDF D→Kp $_0$
soon expected



SM $O(10^{-3})$

G. Burdman and I. Shipsey
Ann. Rev. Nucl. Part. Sci. **53** 431 (2003)
arXivhep-ph/0310076 (updated August 20 2004).

Big potential for CDF (and LHCb)



	D($K^-\pi^+$)
E791	5.6K
FOCUS	37K
CLEO	13.5K
BELLE	83K
BABAR	120K

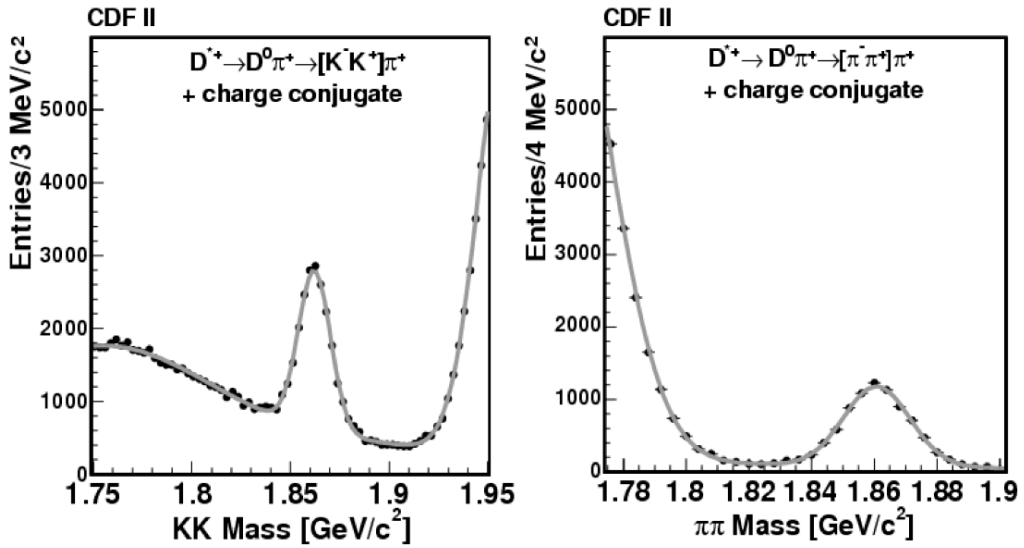
LHCb: 2 fb^{-1}: $K^-\pi^+$: 21M events

B factories by 2008 3M events

CP violation in D decay amplitudes

$$A_{CP} \equiv \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D^0} \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D^0} \to f)}$$

	A_{CP}(KK) [%]	A_{CP}(ππ) [%]
CLEO	0.0±2.2±0.8	1.9±3.2±0.8
E791	−1.0±4.9±1.2	−4.9±7.8±2.5
FOCUS	−0.1±2.2 ± 1.5	4.8±3.9±2.5
CDF	2.0±1.7±0.6	1.0±1.3±0.6



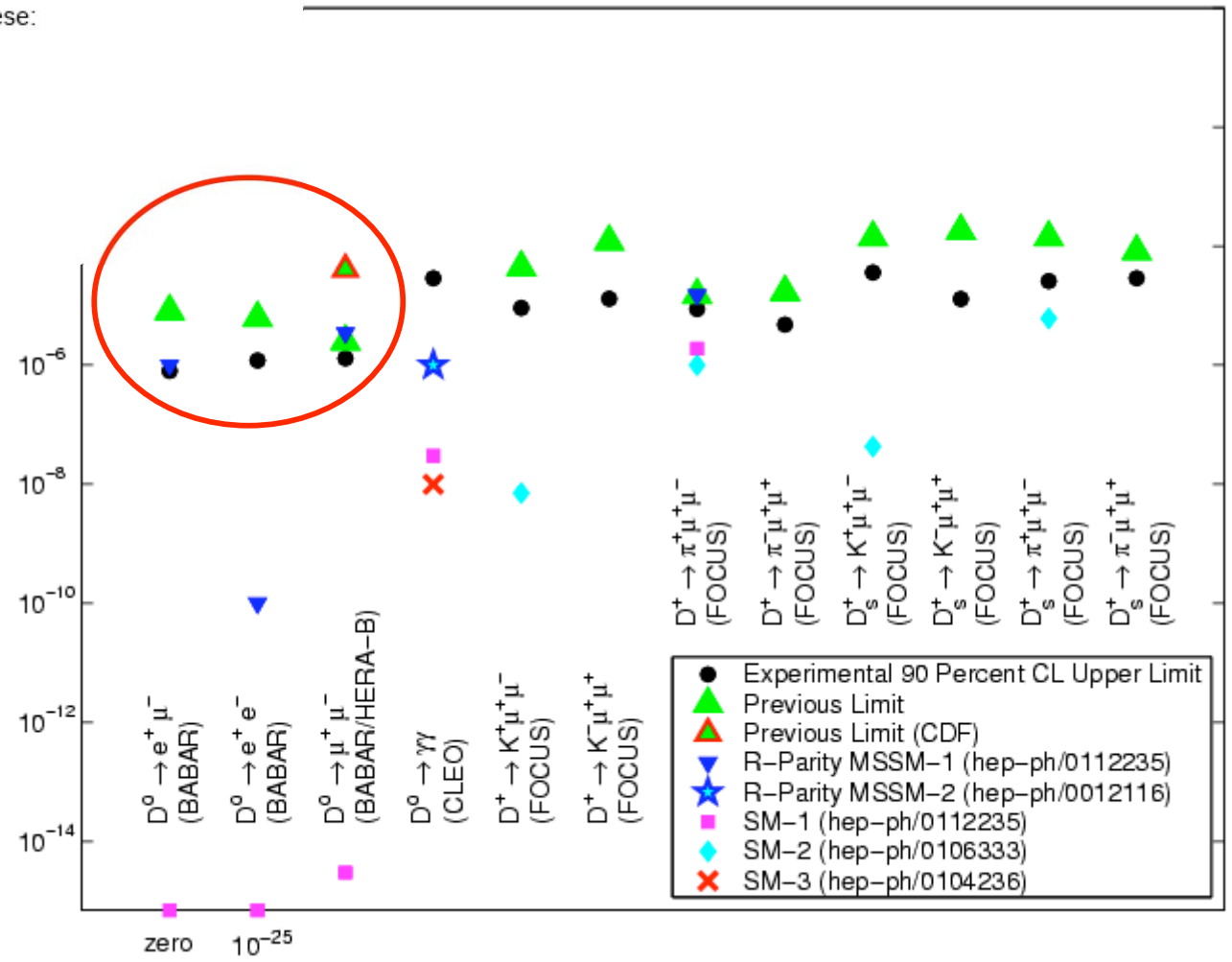
Rare D decay

Beyond the Standard Model, New Physics may enhance these, e.g.,

- R-parity violating SUSY could increase these:
  - $\mathcal{B}(D^0 \to e^+e^-)$ up to 10^{-10}
  - $\mathcal{B}(D^0 \to \mu^+\mu^-)$ up to 10^{-6}.
  - $\mathcal{B}(D^0 \to e^\pm\mu^\mp)$ up to 10^{-6}.

  [Burdman *et al*, Phys. Rev. D66, 014009]

- LHCb could improve limits by a factor of >100 !



Conclusions

QCD description of production and decay are well advancing.

Will be continued by (~2006)

H1 and ZEUS (HERA)

CDF and D0 (TeVatron)

BABAR and BELLE (B factories)

CLEOc and BES

Precise extraction of the CKM matrix elements

- from the decay
  - BABAR and BELLE (B factories)
  - CLEOc and BES
- oscillations
  - CDF and D0
  - BARBAR and BELLE
- from CP violation
  - CDF and D0
  - BARBAR and BELLE

Search for new physics through rare phenomena

10^8-10^9 B's

D-$\overline{\text{D}}$ oscillations

CDF/D0, BABAR/BELLE

CP violation

BABAR/BELLE, CDF/D0

Very rare decays, forbidden decays

CDF/D0, BABAR/BELLE

(leptonic decays)

followed by LHCb (>2007) and later BTeV (>2009)

10^9-10^{10} B's

CP violation in the B_s system

D-$\overline{\text{D}}$ oscillations

Very rare decays, forbidden decays

and Super B factories? (>2010)

-My very personal view-

If there will be fix target heavy flavour experiments in future…

they will not be competitive for new physics search.
there is always to thing to do for QCD.