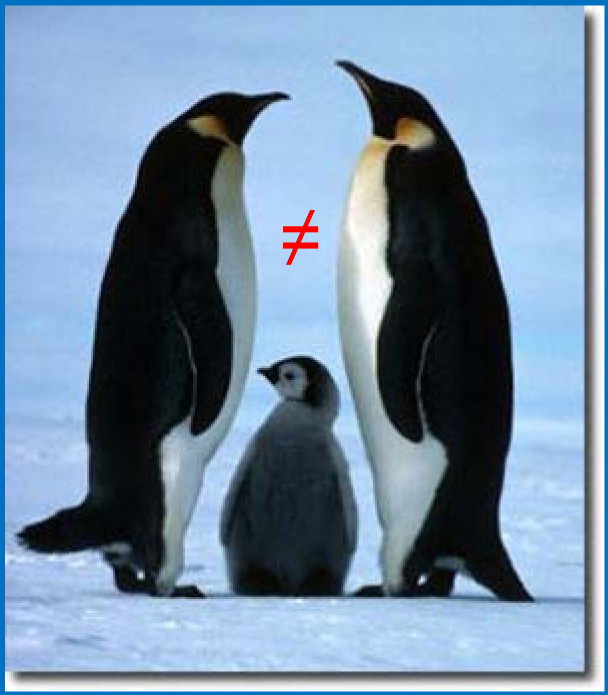
CP Violation in B^0_s mesons

Results from flavor tagged analyses of $B^0_s \rightarrow J/\psi\ \phi$

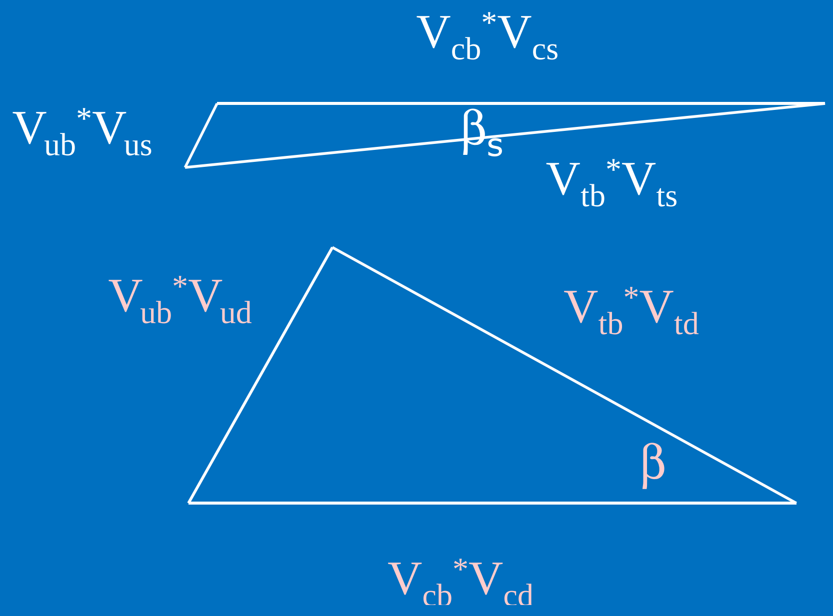
Joe Boudreau
University of Pittsburgh
For the CDF and D0 Collaborations



A very brief abstract of this talk first. The following topics will be developed:

CDF and D0 use $B^0_s \to J/\psi\ \phi$ to measure CKM phases. We determine from this decay the quantity β_s.

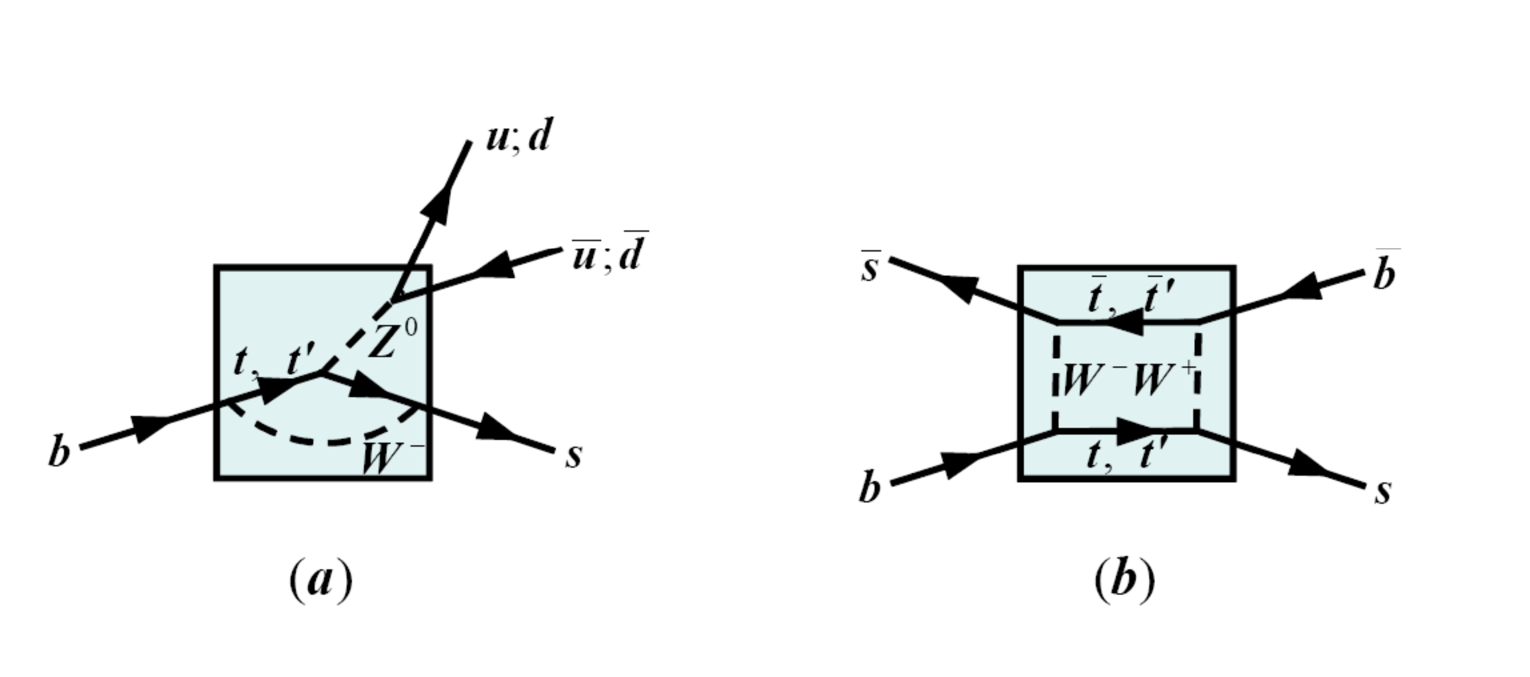
This is in exact analogy to B factory measurement of the β, an angle of the unitarity triangle.



The standard model makes very precise predictions for both angles.

But other new particles & processes, lurking potentially in quantum mechanical loops such as *box diagrams* and *penguin diagrams* can change the prediction.

Example of new physics: a fourth generation quark that contributes to the mixing phase



Wei-Shu Hou, arXiv:hep-ph/0803.1234

Would have other measureable consequences: e.g. an impact on direct CP violation in $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$

$B^0_s \rightarrow J/\psi\ \phi$

* $B^0_s \rightarrow J/\psi\ \phi$ is two particles decaying to three final states..

Two particles:

$$\left|B^0{}_{S,L}\right\rangle = p\left|B_S{}^0\right\rangle + q\left|\bar{B}_S{}^0\right\rangle$$

$$\left|B^0{}_{S,H}\right\rangle = p\left|B_S{}^0\right\rangle - q\left|\bar{B}_S{}^0\right\rangle$$

Light, CP-even, shortlived in SM

Heavy, CP-odd, longlived in SM

Three final states:		
	$J/\psi\ \phi$ in an S wave	CP Even
	$J/\psi\ \phi$ in a D wave	CP Even
	$J/\psi\ \phi$ in a P wave	CP Odd

Manifestations of CP violation in $B^0_s \rightarrow J/\psi\ \phi$

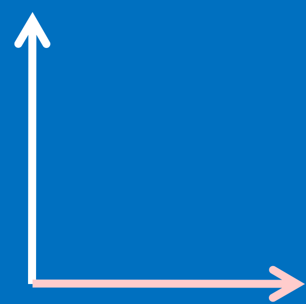
A supposedly CP even initial state decays to a supposedly CP odd final state…. like the neutral kaons

Measurement needs $\Delta\Gamma \neq 0$ but not flavor tagging.

The polarization of the two vector mesons in the decay evolves with a frequency of Δm_s

Measurement needs flavor tagging, resolution, and knowledge of Δm_s

Time dependence of the angular distributions: use a basis of linear polarization states of the two vector mesons $\{ S, P, D\} \rightarrow \{ \mathscr{P}_{\perp}, \mathscr{P}_{||}, \mathscr{P}_{0} \}$



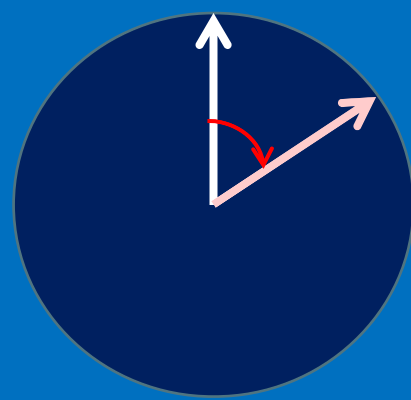
CP odd states decay to $\mathscr{P}_{\perp}$

CP even states decay to $\mathscr{P}_{||}$, $\mathscr{P}_{0}$

If [H,CP] ≠ 0

Then $\boxed{\frac{d}{dt}\langle CP \rangle \neq 0}$

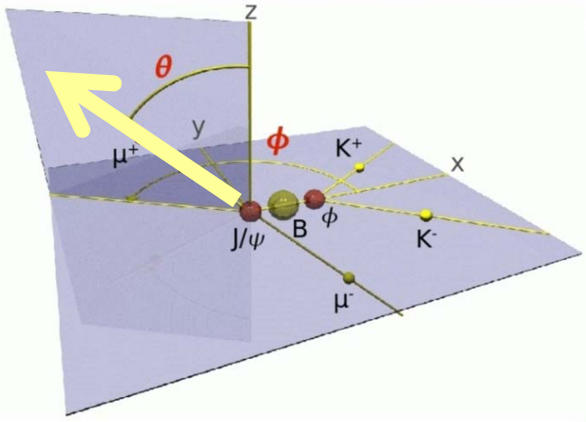
$\Delta m_s \sim 17.77\ ps^{-1}$.

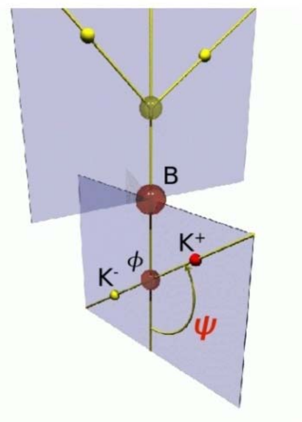


- The polarization correlation depends on decay time.
- Angular distribution of decay products of the J/ψ and the ϕ analyze the rapidly oscillating correlation.

A. S. Dighe, I. Dunietz, H. J. Lipkin, and J. L. Rosner, Phys. Lett. B 369, 144 (1996), 184 hep-ph/9511363.

The measurement is an analysis of time-dependent angular distributions





$$\hat{n} = (\sin\theta\cos\varphi, \sin\theta\sin\phi, \cos\theta)$$

$$\vec{A} = (A_0(t)\cos\psi, \frac{-A_{\parallel}(t)\sin\psi}{\sqrt{2}}, i\frac{A_{\perp}(t)}{\sqrt{2}})$$

$$P(\theta,\phi,\psi,t) = \frac{9}{16\pi}|\vec{A}(t)\times\hat{n}|^2$$

… formula suggests an analysis of an oscillating polarization.

This innocent expression hides a lot of richness:

* CP Asymmetries through flavor tagging.
* sensitivity to ~~CP~~ without flavor tagging.
* sensitivity to *both* $\sin(2\beta_s)$ and $\cos(2\beta_s)$ simultaneously.
* Width difference
* Mixing Asymmetries

CP Violation in the interference of mixing and decay for the B^0_s system

Take: q/p from the mixing of $\overline{B^0}_s$ - B^0_s

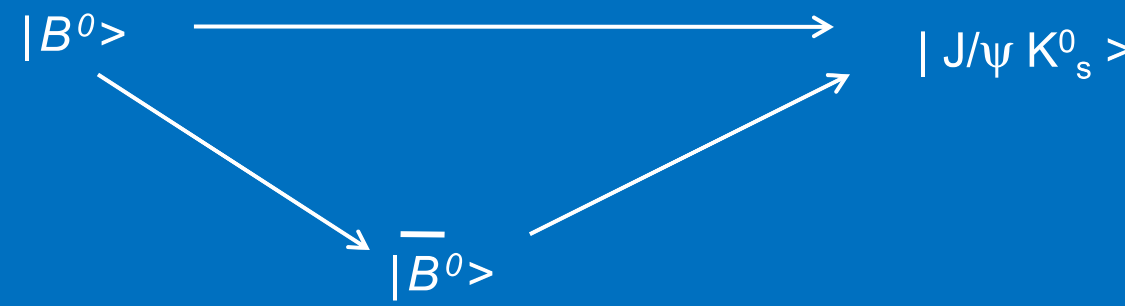
Take: $\bar{A}/A$ from the decay into $\{ \mathscr{P}_\perp, \mathscr{P}_{||}, \mathscr{P}_0 \}$

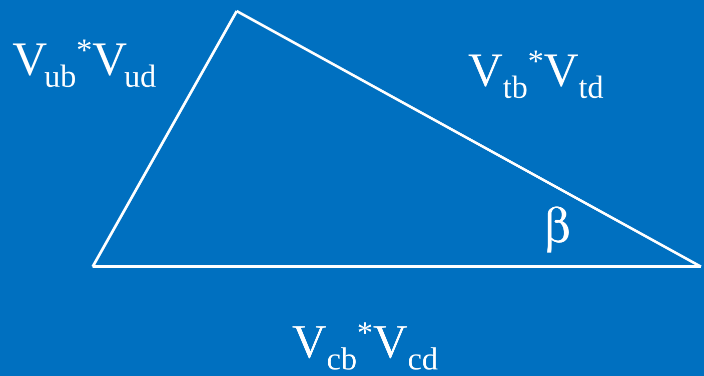
Form: the (phase) convention-independent and observable quantity:

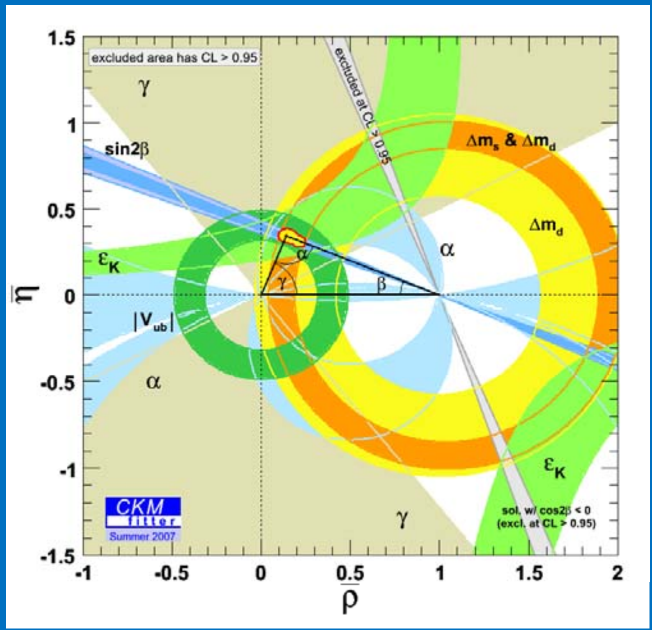
$$\lambda = \frac{q}{p}\frac{\bar{A}}{A}$$

This number is real and unimodular if [H,CP]=0

Very famous measurement of CP Asymmetries in $B^0 \rightarrow J/\psi\ K^0_s$







BABAR, BELLE have used this decay to measure precisely the value of $\sin(2\beta)$ an angle of the **bd** unitarity triangle.

There was a fourfold ambiguity

http://ckmfitter.in2p3.fr/

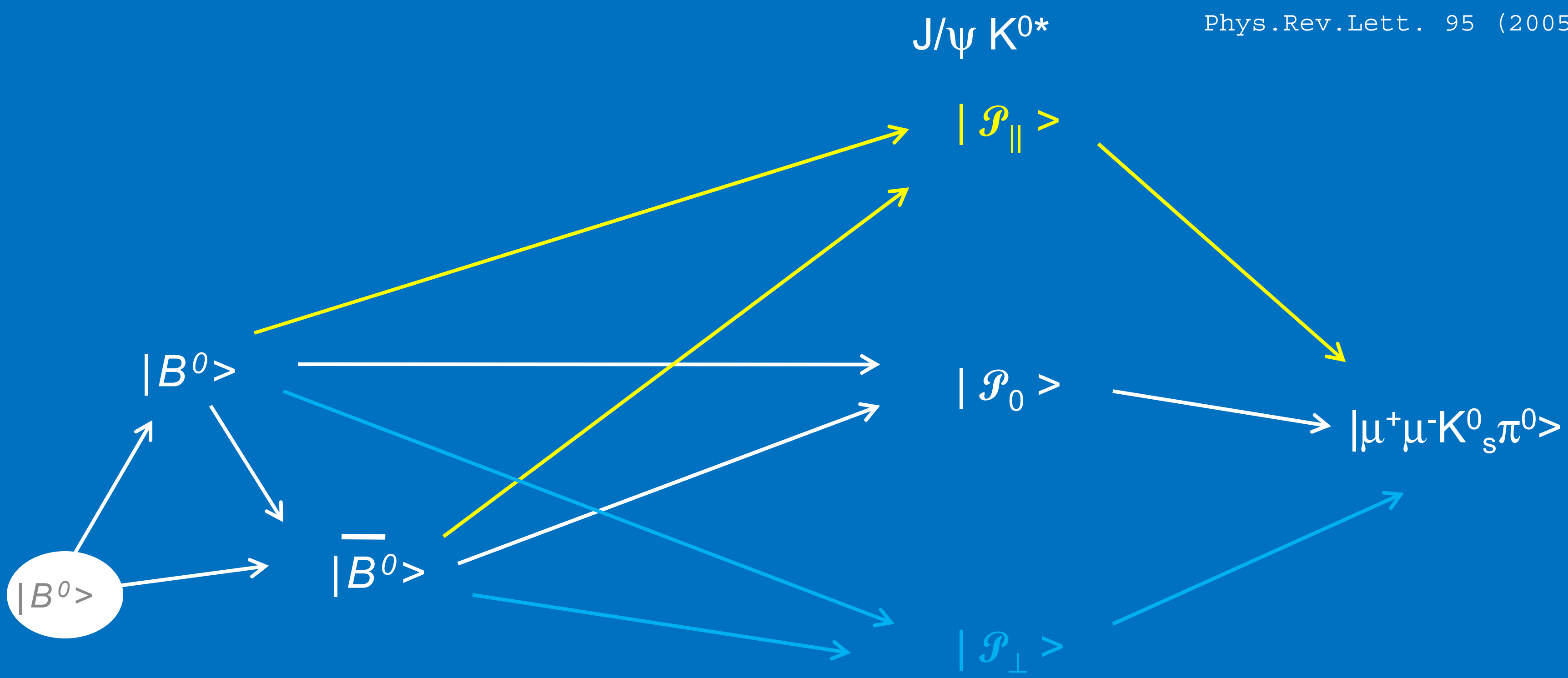
Babar, Belle resolve an ambiguity in β by analyzing the decay

$B^0 \to J/\psi\, K^{0*}$ which is $B \to V\, V$ and measures $\sin(2\beta)$ and $\cos(2\beta)$

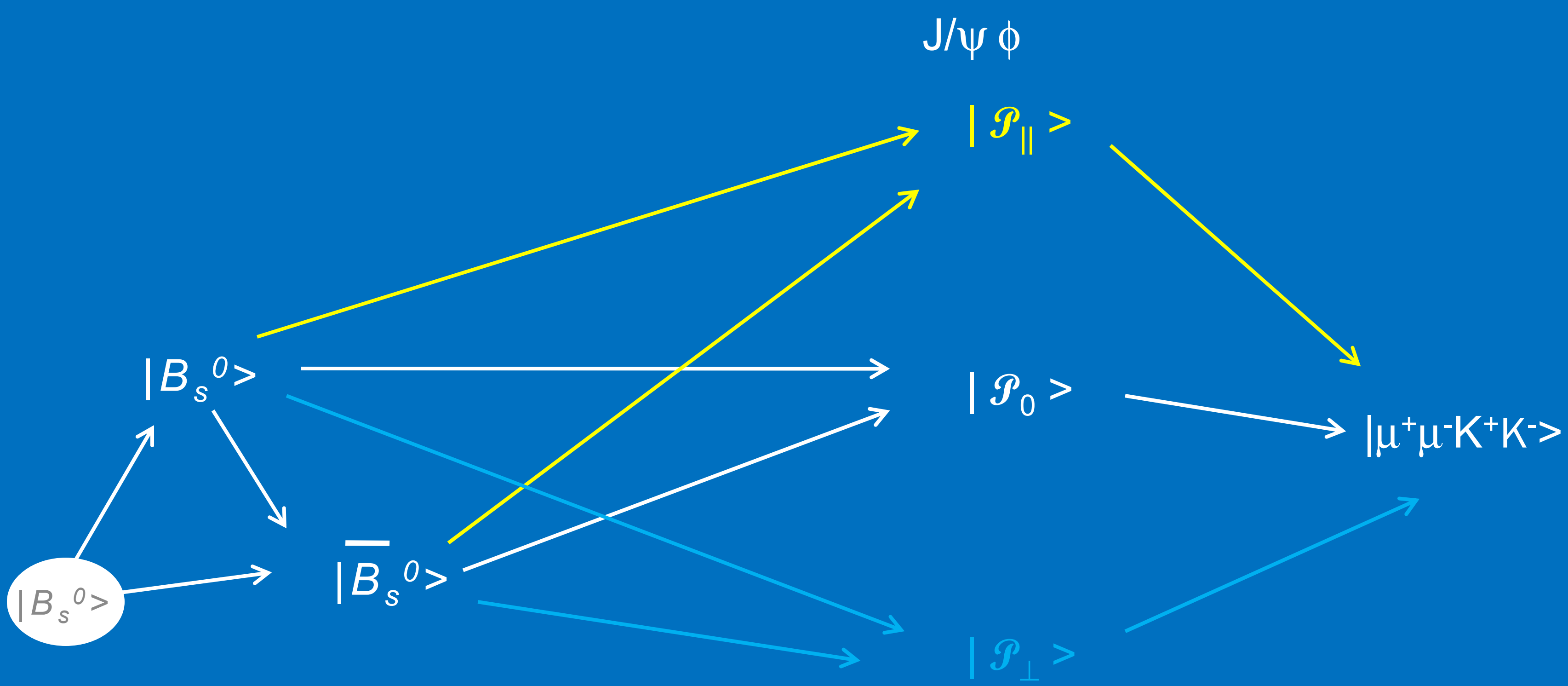
This involves angular analysis as described previously

Phys.Rev. D71 (2005) 032005

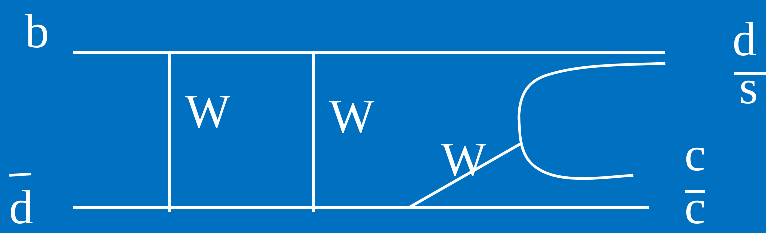
Phys.Rev.Lett. 95 (2005) 091601



Today I will tell you about an analysis of an almost exact analogy, $|B_s{}^0\rangle \rightarrow J/\psi\,\phi$ (but I think that in the $B^0{}_s$ system the phenomenology is even richer! Because of the width difference!)

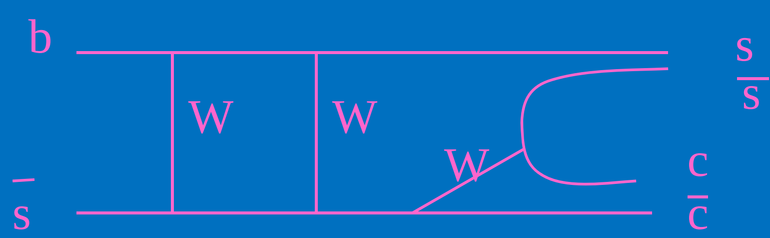


The decay $B^0_s \to J/\psi\,\phi$ obtains from the decay $B^0 \to J/\psi\, K^{0*}$ by the replacement of a d antiquark by an s antiquark



$B^0 \to J/\psi\, K^{0*}$

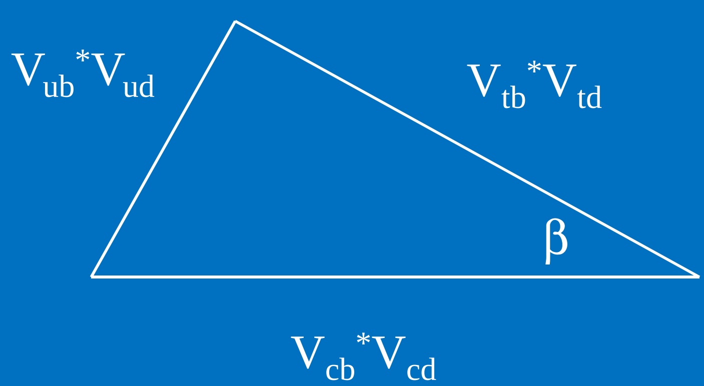
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

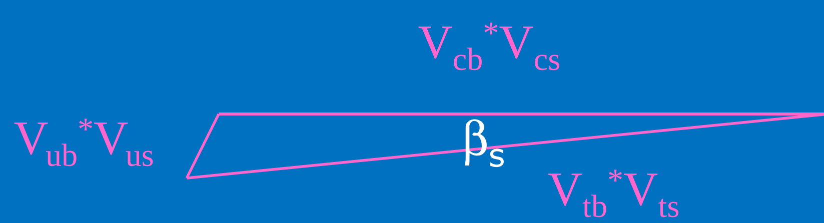


$B_s^0 \to J/\psi\, \phi$

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

We are measuring then not the (bd) unitarity triangle but the (bs) unitarity triangle:





The analysis of $B^0_s \to J/\psi\ \phi$ can extract these physics parameters:

β_s	CP phase
$\Delta\Gamma = \Gamma_H - \Gamma_L$	Width difference
$\tau = 2/(\Gamma_H + \Gamma_L)$	Average lifetime
$A_\perp$ (phase $\delta_\perp$)	Decay Amplitude t=0
$A_\parallel$ (phase $\delta_\parallel$)	Decay Amplitude t=0
A_0 (phase 0)	Decay Amplitude t=0

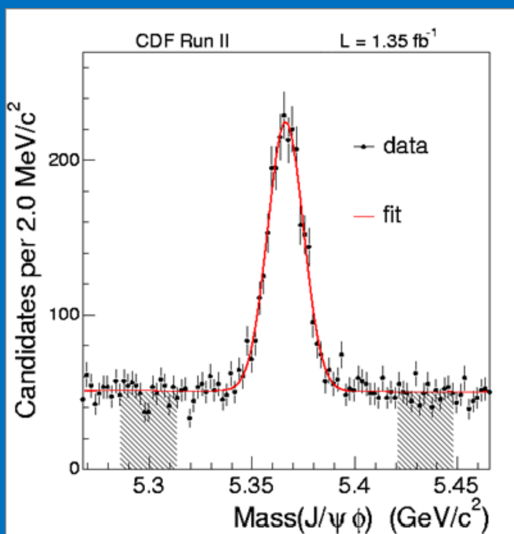
The measurement of β_s and $\Delta\Gamma$ are correlated; from theory one has the relation $\Delta\Gamma = 2|\Gamma_{12}|\cos(2\beta_s)$ with $|\Gamma_{12}| = 0.048 \pm 0.018$ and

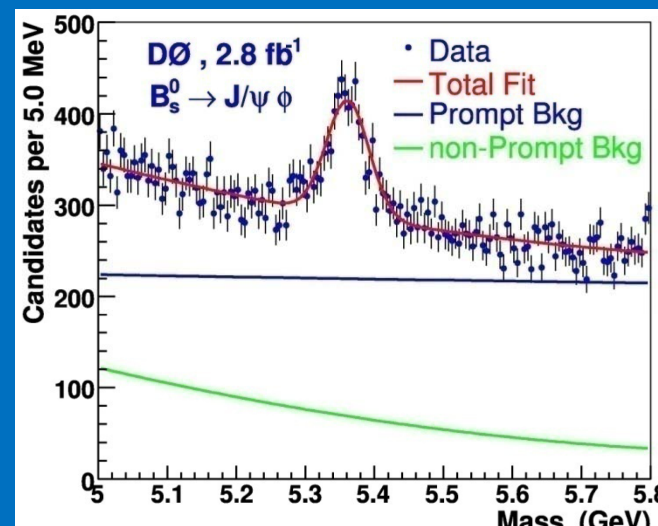
A. Lenz and U. Nierste, J. High Energy Phys. 0706, 072 (2007).

The exact symmetry..

$$\begin{aligned} \beta_s &\to \frac{\pi}{2} - \beta_s, \\ \Delta\Gamma &\to -\Delta\Gamma, \\ \delta_{\|} &\to 2\pi - \delta_{\|}, \\ \delta_\perp &\to \pi - \delta_\perp. \end{aligned}$$

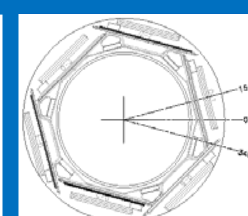
... is an experimental headache.



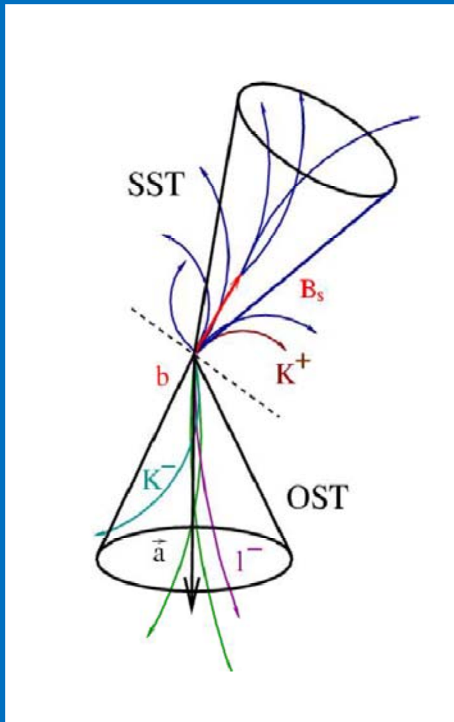


2019 ± 73 events

1967 ± 65 events



Flavor Tagging

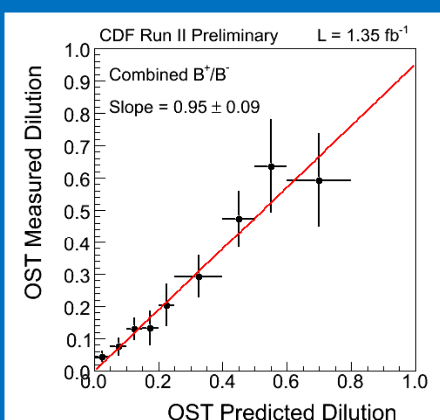


SST +OST: $\varepsilon D^2 = 4.68 \pm 0.54\%$

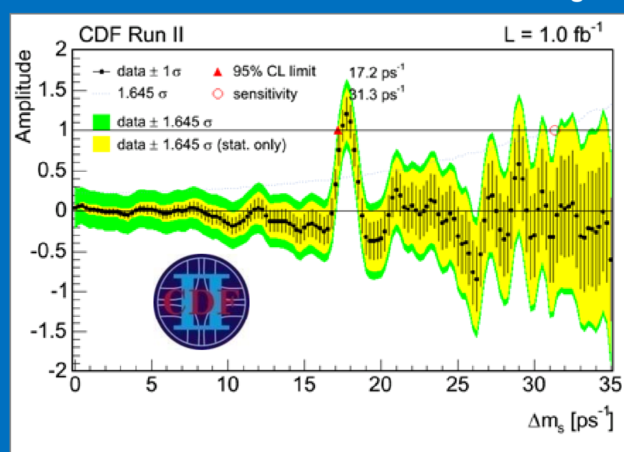
SST: $\varepsilon D^2 \cong 3.6\%$
OST: $\varepsilon D^2 \cong 1.2\%$

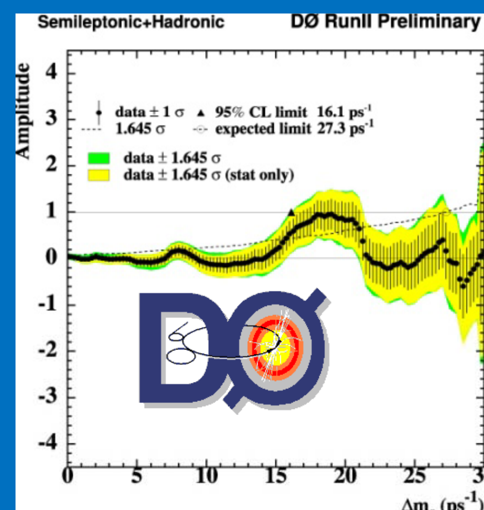
Each tag decision comes with an error estimate validated:

1. Using $B^{\pm}$ (OST)



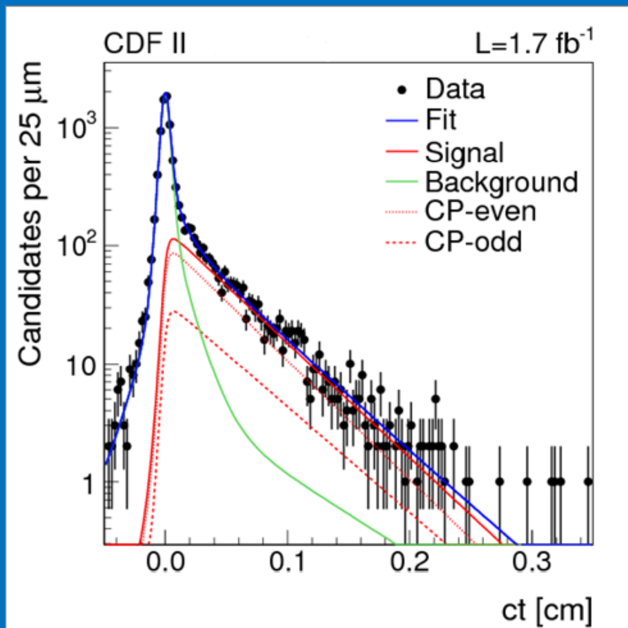
2. In the B^0_s mixing (SST)





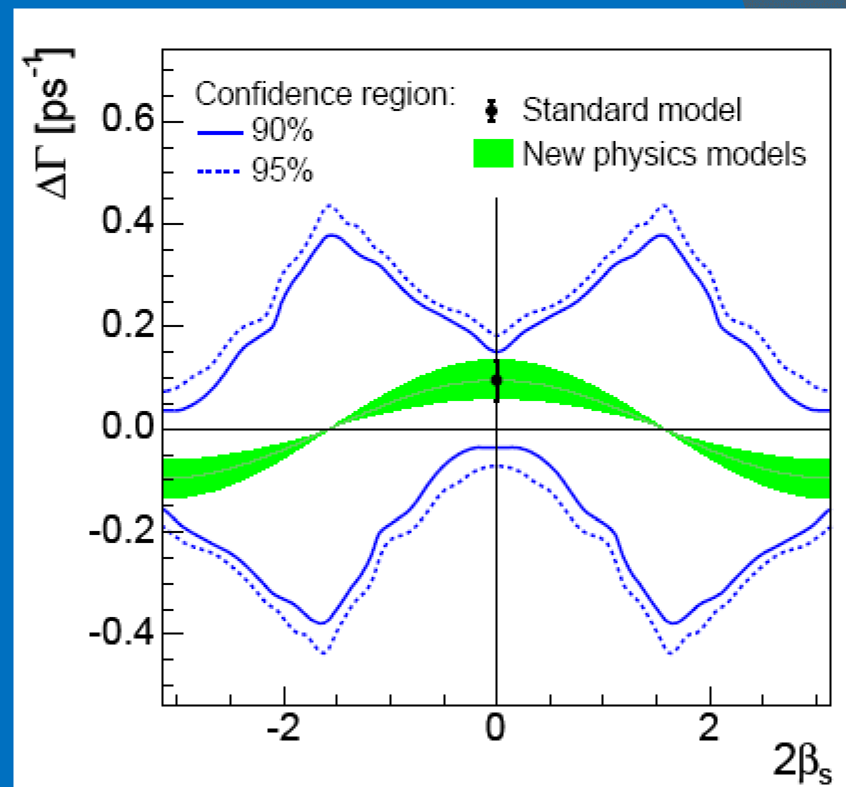
CDF Untagged Analysis (1.7 fb^{-1})

Phys. Rev. Lett. 100, 121803 (2008)



$$c\tau_s = 456 \pm 13 \pm 7\ \mu\mathrm{m}$$
$$\Delta\Gamma = 0.076^{+0.059}_{-0.063} \pm 0.006\ \mathrm{ps}^{-1}$$
$$|A_0|^2 = 0.530 \pm 0.021 \pm 0.007$$
$$|A_{||}|^2 = 0.230 \pm 0.027 \pm 0.009$$

Feldman-Cousins confidence region in the space of the parameters $2\beta_s$ and $\Delta\Gamma$

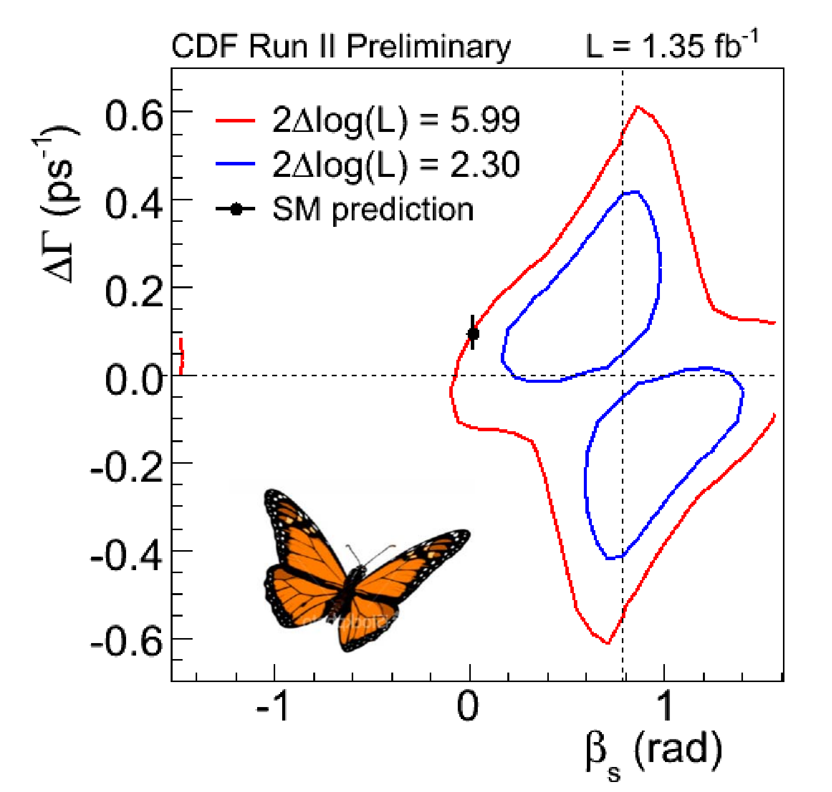


HQET: $c\tau(B^0_s) = (1.00\pm0.01)\ c\tau(B^0)$

PDG: $c\tau(B^0) = 459 \pm 0.027\ \mu$m

Tagged analysis: likelihood contour in the space of the parameters β_s and $\Delta\Gamma$

Phys. Rev. Lett. 100, 161802 (2008)



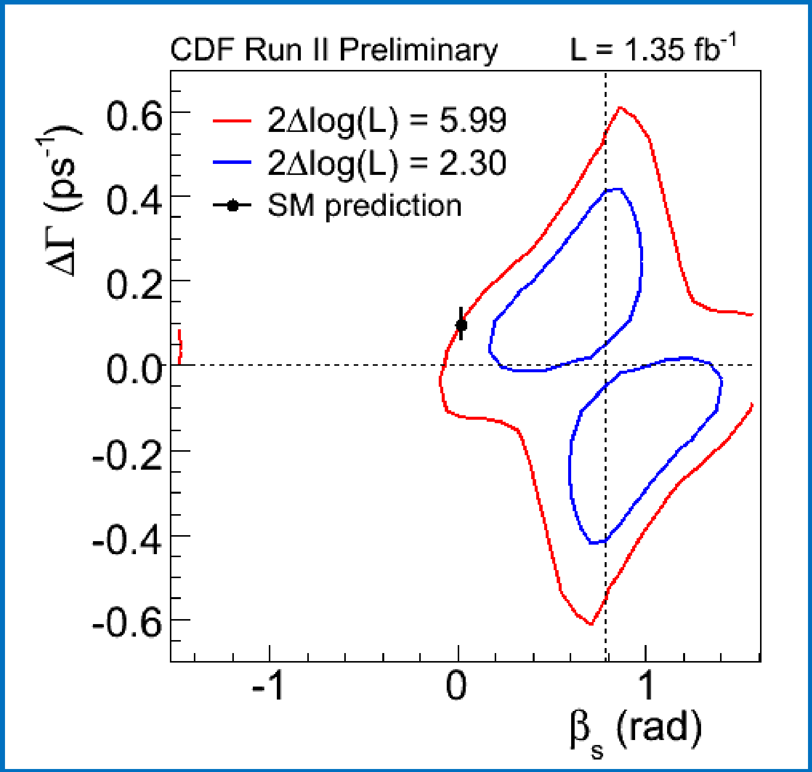
One ambiguity is gone, now this one

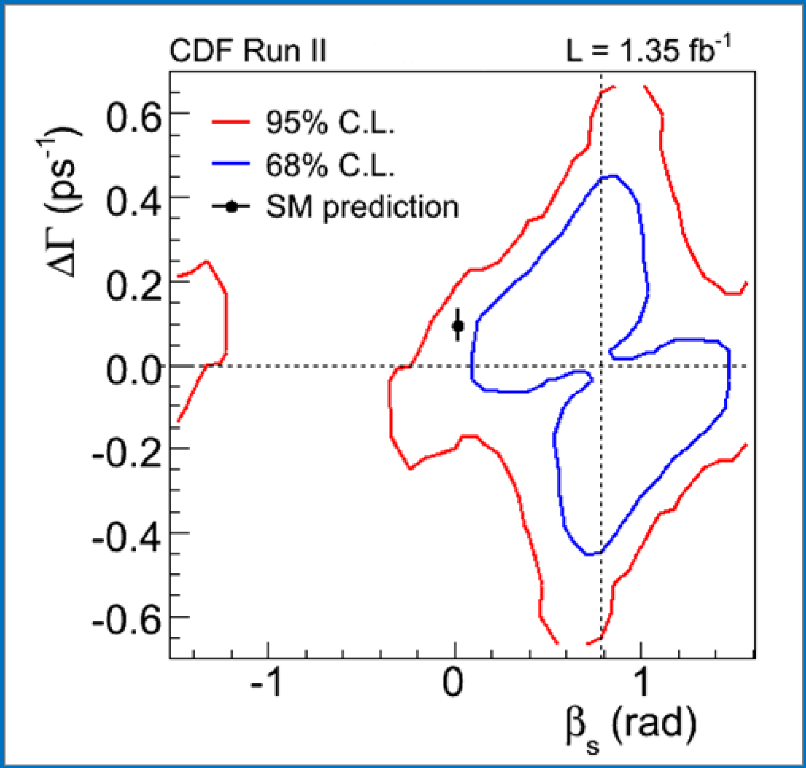
$$
\begin{aligned}
\beta_s &\to \frac{\pi}{2} - \beta_s, \\
\Delta\Gamma &\to -\Delta\Gamma, \\
\delta_{\|} &\to 2\pi - \delta_{\|}, \\
\delta_{\perp} &\to \pi - \delta_{\perp}.
\end{aligned}
$$

remains

A frequentist confidence region in the β_s-$\Delta\Gamma$ including systematic errors is the main result. This interval is based on p-values obtained from Monte Carlo and represents regions that contain the true value of the parameters 68% (95%) of the time.

arXiv:0712.2397v1

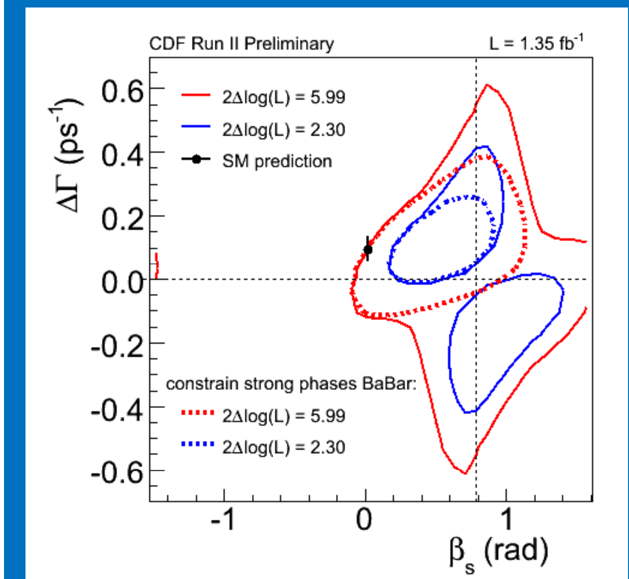




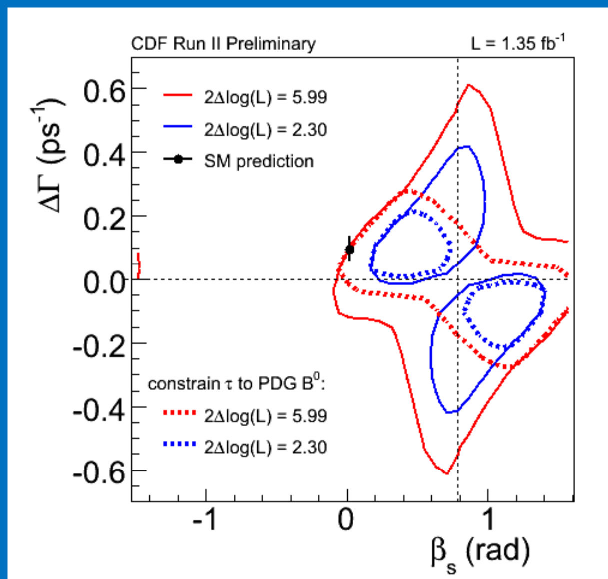
The standard model agrees with the data at the 15% CL

There is no way that this measurement can remove the remaining ambiguity alone. External constraints on the phases, from B factories, can do, but they may not be applicable:

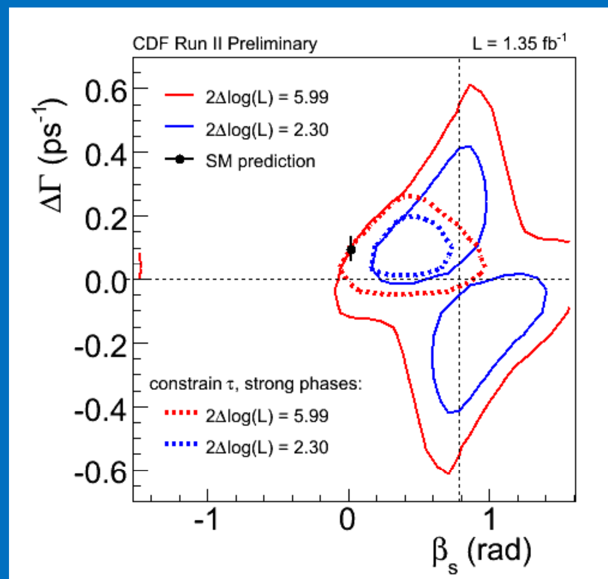
Constrain strong phases $\delta_{||}$ and $\delta_{\perp}$ to BaBar Values (for $B^0 \to J/\psi\ K^*$)



Constrain τ_s to PDG Value for B^0



Apply both constraints.



using values reported in:

B. Aubert et al. (BABAR Collaboration), Phys. Rev. D 71, 032005 (2005).

The D0 Result is a confidence interval using an external constraint:

Strong phases varying around the world average values (for $B^0 \to J/\psi\ K^*$); Gaussian constraint with $\sigma=\pi/5$ is applied.

D0 Result

$\phi_s = -2\beta_s$

arXiv:0802.2255

Prev result: PRD 76, 057101 (2007)

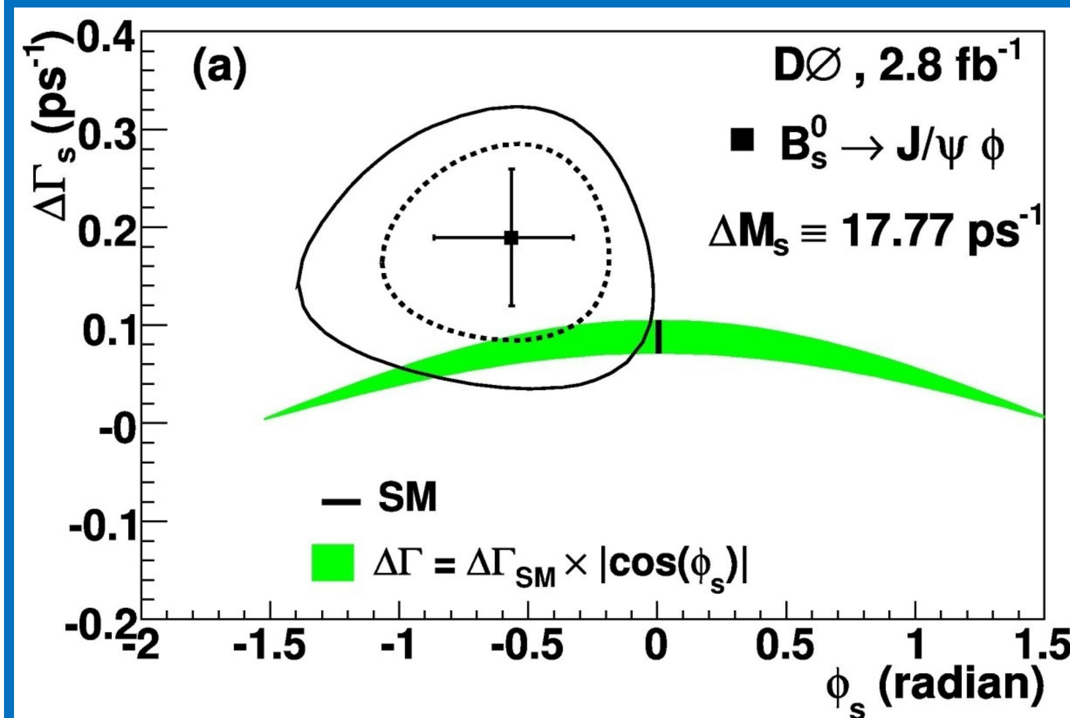


TABLE I: Summary of the likelihood fit results for three cases: free ϕ_s, ϕ_s constrained to the SM value, and $\Delta\Gamma_s$ constrained by the expected relation $\Delta\Gamma_s^{SM} \cdot |\cos(\phi_s)|$.

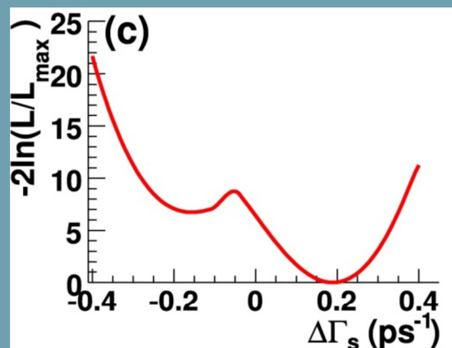
	free ϕ_s	$\phi_s \equiv \phi_s^{SM}$	$\Delta\Gamma_s^{th}$
$\overline{\tau}_s$ (ps)	1.52±0.06	1.53±0.06	1.49±0.05
$\Delta\Gamma_s$ (ps^{-1})	0.19±0.07	0.14±0.07	0.083 ± 0.018
$A_\perp(0)$	0.41±0.04	0.44±0.04	0.45±0.03
$\lvert A_0(0)\rvert^2 - \lvert A_{\lvert\lvert}(0)\rvert^2$	0.34±0.05	0.35±0.04	0.33±0.04
δ_1	−0.52±0.42	−0.48±0.45	−0.47±0.42
δ_2	3.17±0.39	3.19±0.43	3.21±0.40
ϕ_s	$-0.57^{+0.24}_{-0.30}$	$\equiv -0.04$	−0.46 ± 0.28
ΔM_s (ps^{-1})	≡ 17.77	≡ 17.77	≡ 17.77

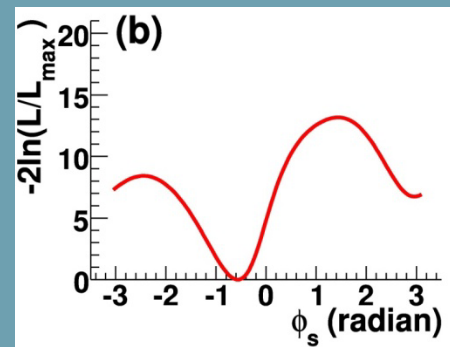
and $0.06 < \Delta\Gamma_s < 0.30$ ps^{-1}. To quantify the level of agreement with the SM, we use pseudo-experiments with the "true" value of the parameter ϕ_s set to -0.04. We find the probability of 6.6% to obtain a fitted value of ϕ_s lower than -0.57.

Contours are 68% CL and 90% CL

1 D Contours & Confidence Intervals

Likelihood contours for just $\Delta\Gamma$ and for just ϕ_s=-2β_s





$\Delta\Gamma$=0.19 ±0.07 ps^{-1} ϕ_s=-0.57 $^{+0.24}_{-0.30}$

FC Confidence Intervals:

(1) 2β_s □ [0.32, 2.82] at the 68% CL.

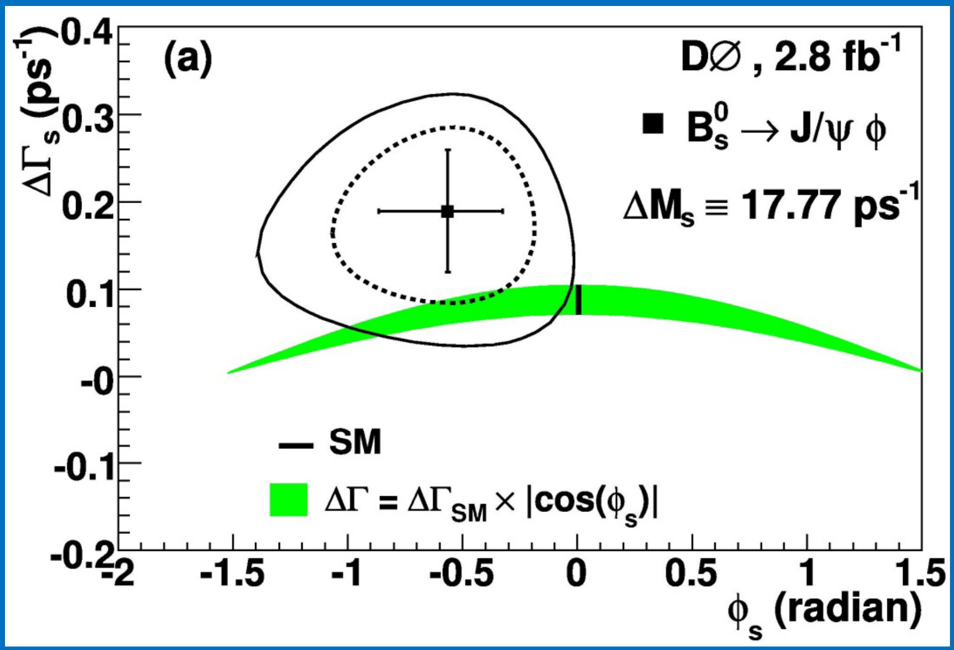
Assuming $|\Gamma_{12}|$ = 0.048 ± 0.018 and the relation $\Delta\Gamma = 2|\Gamma_{12}|\cos(2\beta_s)$:

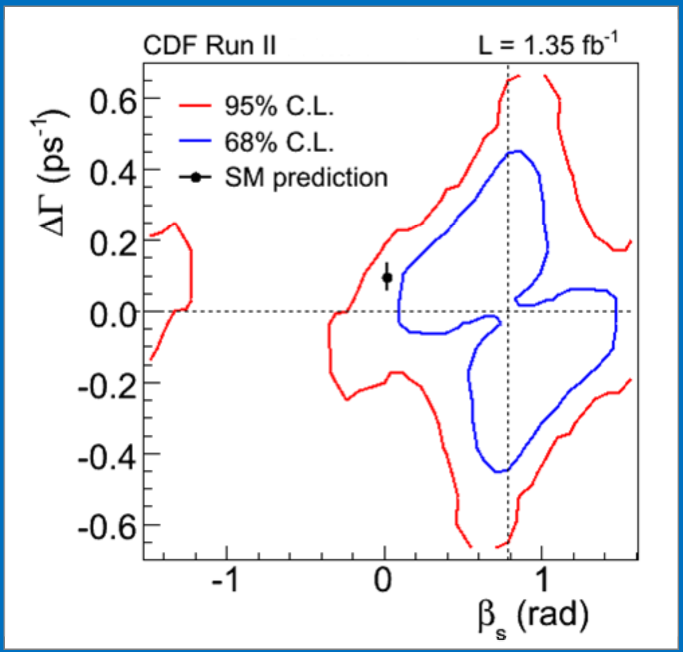
(2) 2β_s □ [0.24,1.36] U [1.78, 2.90] at the 68% CL.

Constrain $\delta_{||}$ and $\delta_{\perp}$ to the results from $B^0 \rightarrow J/\psi\, K^{*0}$ decays & $\tau_s = \tau_d$

(3) 2β_s □ [0.40, 1.20] at 68% CL

Outlook





Note $\phi_s = -2\beta_s$

- Fluctuation or something more, it does go in the same direction.
- CDF estimates a p-value of 15% for the standard model, using Monte Carlo
- D0 estimates a p-value of 6.6% using Monte Carlo

UTFit group has made an “external” combination.

arXiv:hep-ph/0803.0659

We combine all the available experimental information on B_s mixing, including the very recent tagged analyses of $B_s \to J/\Psi\phi$ by the CDF and DØ collaborations. We find that the phase of the B_s mixing amplitude deviates more than $\boxed{3\sigma}$ from the Standard Model prediction. While no single measurement has a 3σ significance yet, all the constraints show a remarkable agreement with the combined result. This is a first evidence of physics beyond the Standard Model. This result disfavours New Physics models with Minimal Flavour Violation with the same significance.

- “re-introduces” the ambiguity into the D0 result.
- does so by symmetrizing.
- cannot fully undo the strong phase constraint.

- I am showing you this conclusion, but not endorsing it very enthusiastically.

D0 is now producing a result without the strong phase constraint.

HFAG is preparing to combine the two unconstrained results

Further comments:

- We have assumed so far that:

$$\lambda = \frac{q}{p}\frac{\bar{A}}{A} = e^{2i\beta_s}$$

and thus $|\lambda| = 1$ .. To a very good approximation. In higher order however $|q| \neq |p|$ and $|\lambda| \neq 1$ (at the level of $1-|\lambda| < 2.5 \times 10^{-3}$)

Semileptonic asymmetry:

$$\mathcal{A}_{\rm SL}(t) \equiv \frac{d\Gamma/dt\left[\overline{M}^0_{\rm phys}(t) \to \ell^+ X\right] - d\Gamma/dt\left[M^0_{\rm phys}(t) \to \ell^- X\right]}{d\Gamma/dt\left[\overline{M}^0_{\rm phys}(t) \to \ell^+ X\right] + d\Gamma/dt\left[M^0_{\rm phys}(t) \to \ell^- X\right]} = \frac{1-|q/p|^4}{1+|q/p|^4}.$$

$$A_{sl} = \frac{\Gamma^s{}_{12}}{M^s{}_{12}}\sin(\varphi_s)$$

HQET: $\Gamma_{12}/M^s_{12} = (49.7 \pm 9.4) \pm 10^{-4}$

- $A^s_{SL} = 0.020 \pm 0.028$ (CDF)

http://www-cdf.fnal.gov/physics/new/bottom/070816.blessed-acp-bsemil/

- $A^s_{SL} = 0.0001 \pm 0.0090$ (stat) (D0)

Phys. Rev. D 76, 057101 (2007)

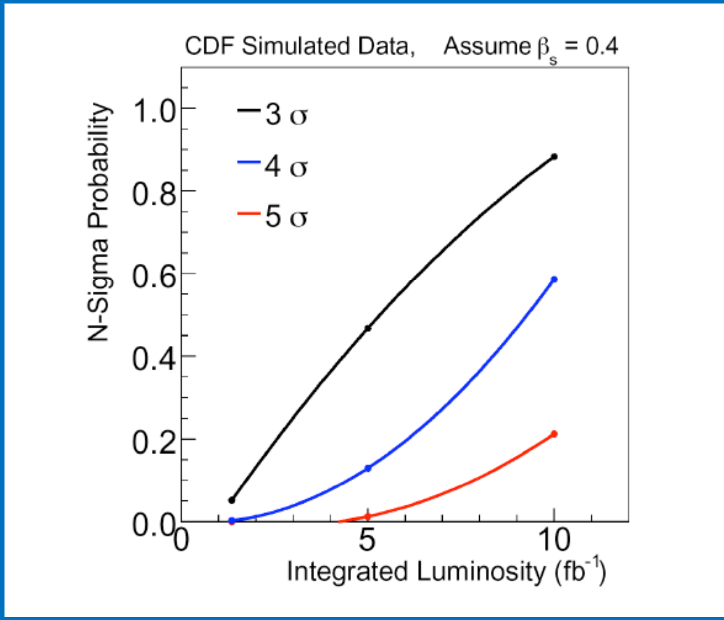
Conclusion

• Towards the end of a 20-year program in proton-antiproton physics: some terribly interesting times for the physics of the b-quark.

• An anomaly from the B factories Lin, S.-W. *et al. Nature 452*,332-335 (2008).
• Are quantum loop corrections to the $b \rightarrow s$ transitions to blame?

• If so, precision measurements of the CP asymmetries in the B^0_s system are a clean way to sort it out.

• D0 and CDF have just demonstrated the feasibility of doing those measurements; more work needed now to understand the true significance.



• Higher precision, higher statistics measurements could give us a even stronger hint as the LHC begins taking data.

FIN

Free Bonus Slides

$$\hat{n} = (\sin\theta\cos\varphi, \sin\theta\sin\varphi, \cos\theta)$$

$$\vec{A}(t) = (A_0(t)\cos\psi, -\frac{A_\parallel(t)\sin\psi}{\sqrt{2}}, i\frac{A_\perp(t)}{\sqrt{2}})$$

$$P(\theta,\varphi,\psi,t) = \frac{9}{16\pi}|\vec{A}(t)\times\hat{n}|^2$$

An analysis of the decay can be done with either a mix of B and $\overline{\text{B}}$ mesons (untagged) or with a partially separated sample (flavor tagged). Latter is more difficult and more powerful.

$$A_i(t) = \frac{a_i e^{-imt} e^{-\Gamma t/2}}{\sqrt{\tau_H + \tau_L \pm \cos 2\beta_s \cdot (\tau_L - \tau_H)}}\left[E_+(t) \pm e^{2i\beta_s} E_-(t)\right]$$ B

$$\bar{A}_i(t) = \frac{a_i e^{-imt} e^{-\Gamma t/2}}{\sqrt{\tau_H + \tau_L \pm \cos 2\beta_s \cdot (\tau_L - \tau_H)}}\left[\pm E_+(t) + e^{-2i\beta_s} E_-(t)\right]\cdot$$ $\overline{\text{B}}$

where i = 0, para, perp and

$$E_\pm(t) = \frac{1}{2}\left[e^{+(\frac{-\Delta\Gamma}{4}+i\frac{\Delta m}{2})t} \pm e^{-(\frac{-\Delta\Gamma}{4}+i\frac{\Delta m}{2})t}\right]$$

These expressions are:

* used directly to generate simulated events.

* expanded, smeared, and used in a Likelihood function.

* summed over B and $\overline{\text{B}}$ (untagged analysis only)

$$\mathbf{A}(t) = \mathbf{A}_+(t) + \mathbf{A}_-(t), \quad \bar{\mathbf{A}}(t) = \bar{\mathbf{A}}_+(t) + \bar{\mathbf{A}}_-(t)$$

$$\mathbf{A}_+(t) = \mathbf{A}_+ f_+(t) = (a_0 \cos\psi, -\frac{a_\| \sin\psi}{\sqrt{2}}, 0) \cdot f_+(t)$$
$$\bar{\mathbf{A}}_+(t) = \bar{\mathbf{A}}_+ \bar{f}_+(t) = (a_0 \cos\psi, -\frac{a_\| \sin\psi}{\sqrt{2}}, 0) \cdot \bar{f}_+(t),$$

$$\mathbf{A}_-(t) = \mathbf{A}_- f_-(t) = (0, 0, i\frac{a_\perp \sin\psi}{\sqrt{2}}) \cdot f_-(t)$$
$$\bar{\mathbf{A}}_-(t) = \bar{\mathbf{A}}_- \bar{f}_-(t) = (0, 0, i\frac{a_\perp \sin\psi}{\sqrt{2}}) \cdot \bar{f}_-(t).$$

obtain the overall time and angular dependence

$$\begin{aligned} P(\theta,\psi,\phi,t) &= \frac{9}{16\pi}\left\{|\mathbf{A}_+(\mathbf{t}) \times \hat{n}|^2 + |\mathbf{A}_-(\mathbf{t}) \times \hat{n}|^2 + 2Re((\mathbf{A}_+(\mathbf{t}) \times \hat{n}) \cdot (\mathbf{A}_-^*(\mathbf{t}) \times \hat{n}))\right\} \\ &= \frac{9}{16\pi}\left\{|\mathbf{A}_+ \times \hat{n}|^2 |f_+(t)|^2 + |\mathbf{A}_- \times \hat{n}|^2 |f_-(t)|^2 + 2Re((\mathbf{A}_+ \times \hat{n}) \cdot (\mathbf{A}_-^* \times \hat{n}) \cdot f_+(t) \cdot f_-^*(t))\right\}. \end{aligned}$$

and

$$\begin{aligned} P(\theta,\psi,\phi,t) &= \frac{9}{16\pi}\left\{|\bar{\mathbf{A}}_+(t) \times \hat{n}|^2 + |\bar{\mathbf{A}}_-(t) \times \hat{n}|^2 + 2Re(\bar{\mathbf{A}}_+(t) \times \hat{n}) \cdot (\bar{\mathbf{A}}_-^*(t) \times \hat{n}))\right\} \\ &= \frac{9}{16\pi}\left\{|\mathbf{A}_+ \times \hat{n}|^2 |\bar{f}_+(t)|^2 + |\mathbf{A}_- \times \hat{n}|^2 |\bar{f}_-(t)|^2 + 2Re((\mathbf{A}_+ \times \hat{n}) \cdot (\mathbf{A}_-^* \times \hat{n}) \cdot \bar{f}_+(t) \cdot \bar{f}_-^*(t)\right\}. \end{aligned}$$

Explicit time dependence is here:

where the diagonal terms are:

$$|\bar{f}_{\pm}(t)|^2 = \frac{1}{2}\frac{(1 \pm \cos 2\beta_s)e^{-\Gamma_L t} + (1 \mp \cos 2\beta_s)e^{-\Gamma_H t} \pm 2\sin 2\beta_s e^{-\Gamma t}\sin \Delta m t}{\tau_L(1 \pm \cos 2\beta_s) + \tau_H(1 \mp \cos 2\beta_s)},$$

$$|f_{\pm}(t)|^2 = \frac{1}{2}\frac{(1 \pm \cos 2\beta_s)e^{-\Gamma_L t} + (1 \mp \cos 2\beta_s)e^{-\Gamma_H t} \mp 2\sin 2\beta_s e^{-\Gamma t}\sin \Delta m t}{\tau_L(1 \pm \cos 2\beta_s) + \tau_H(1 \mp \cos 2\beta_s)}.$$

and the cross-terms, or interference terms, are: $f_+(t)f_-^*(t)$. For $\bar{B}$ and B, those terms are

$$\bar{f}_+(t)\bar{f}_-{}^*(t) = \frac{-e^{-\Gamma t}\cos \Delta m t - i\cos 2\beta_s e^{-\Gamma t}\sin \Delta m t + i\sin 2\beta_s(e^{-\Gamma_L t} - e^{-\Gamma_H t})/2}{\sqrt{[(\tau_L - \tau_H)\sin 2\beta_s]^2 + 4\tau_L\tau_H}},$$

$$f_+(t)f_-^*(t) = \frac{e^{-\Gamma t}\cos \Delta m t + i\cos 2\beta_s e^{-\Gamma t}\sin \Delta m t + i\sin 2\beta_s(e^{-\Gamma_L t} - e^{-\Gamma_H t})/2}{\sqrt{[(\tau_L - \tau_H)\sin 2\beta_s]^2 + 4\tau_L\tau_H}}.$$

… then, replace exp, sin*exp, cos*exp with smeared functions

Curiosity #1: $\cos(2\beta_s)$ is easier to measure than $\sin(2\beta_s)$. It can be done in the untagged analysis for which the PDF contains time dependent terms:

$$|\bar{f}_\pm(t)|^2 = \frac{1}{2}\frac{(1\pm\cos 2\beta_s)e^{-\Gamma_L t} + (1\mp\cos 2\beta_s)e^{-\Gamma_H t} \pm 2\sin 2\beta_s e^{-\Gamma t}\sin\Delta m t}{\tau_L(1\pm\cos 2\beta_s) + \tau_H(1\mp\cos 2\beta_s)},$$

$$|f_\pm(t)|^2 = \frac{1}{2}\frac{(1\pm\cos 2\beta_s)e^{-\Gamma_L t} + (1\mp\cos 2\beta_s)e^{-\Gamma_H t} \mp 2\sin 2\beta_s e^{-\Gamma t}\sin\Delta m t}{\tau_L(1\pm\cos 2\beta_s) + \tau_H(1\mp\cos 2\beta_s)}.$$

Physically this is accessible because one particular lifetime state (long or short) decays to the “wrong” angular distributions. Needs $\Delta\Gamma\neq 0$; no equivalent in $B^0 \to J/\psi\ K^{0*}$.

Some fine print: in the interference term, in an untagged analysis, there is a term including $\sin(2\beta_s)$; however this term does not determine the sign of $\sin(2\beta_s)$ so it does not solve any ambiguity.

Curiosity #2:

Sensitivity to Δm_s (tagged analysis only; *even in the absence of ~~CP~~)*

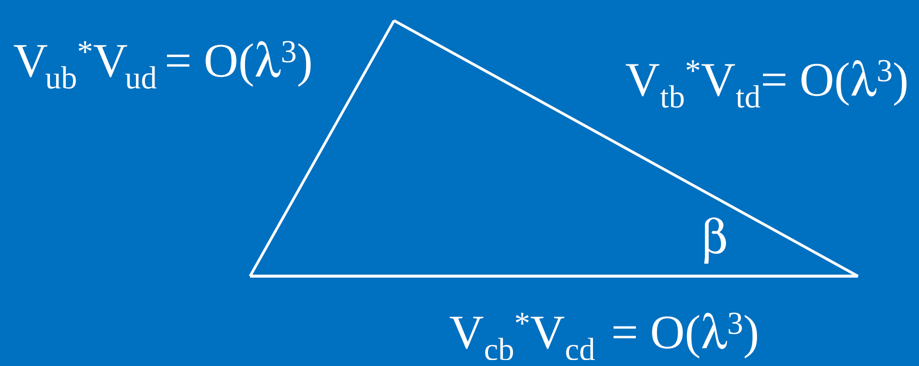
$$\bar{f}_+(t)\bar{f}_-^{\,*}(t) = \frac{-e^{-\Gamma t}\cos\Delta m t - i\cos 2\beta_s e^{-\Gamma t}\sin\Delta m t + i\sin 2\beta_s (e^{-\Gamma_L t} - e^{-\Gamma_H t})/2}{\sqrt{[(\tau_L-\tau_H)\sin 2\beta_s]^2 + 4\tau_L\tau_H}},$$

$$f_+(t)f_-^*(t) = \frac{e^{-\Gamma t}\cos\Delta m t + i\cos 2\beta_s e^{-\Gamma t}\sin\Delta m t + i\sin 2\beta_s (e^{-\Gamma_L t} - e^{-\Gamma_H t})/2}{\sqrt{[(\tau_L-\tau_H)\sin 2\beta_s]^2 + 4\tau_L\tau_H}}.$$

How much sensitivity? Well, we did not exploit it yet but it could be important news at the LHC!

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

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



With $\lambda = 0.2272 \pm 0.0010$
$A = 0.818\ (+0.007\ -0.017)$
$\rho = 0.221\ (+0.064-0.028)$
$\eta = 0.340\ (+0.017-0.045)$

One easily obtains a prediction for β_s :

$$2\beta_s = 0.037 \pm 0.002$$

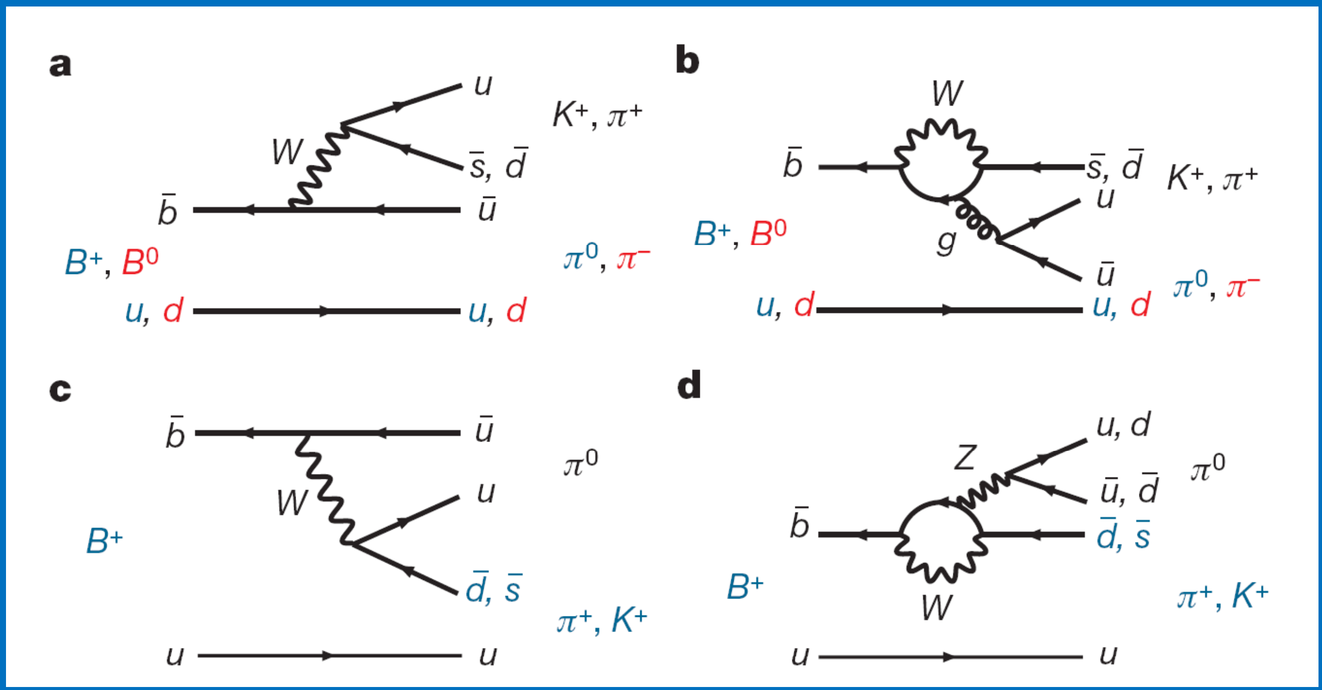
Elsewhere there is another anomaly that *may* also have to do with b→s

* Direct CP in $B^+ \to K^+ \pi^0$ and $B^0 \to K^+\pi^-$ are generated by the b →s transition. These should have the same magnitude.

* But Belle measures $\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037,$ (4.4 σ)

* Including BaBar measurements: > 5σ

Lin, S.-W. *et al. (The Belle collaboration) Nature* 452,332-335 (2008).



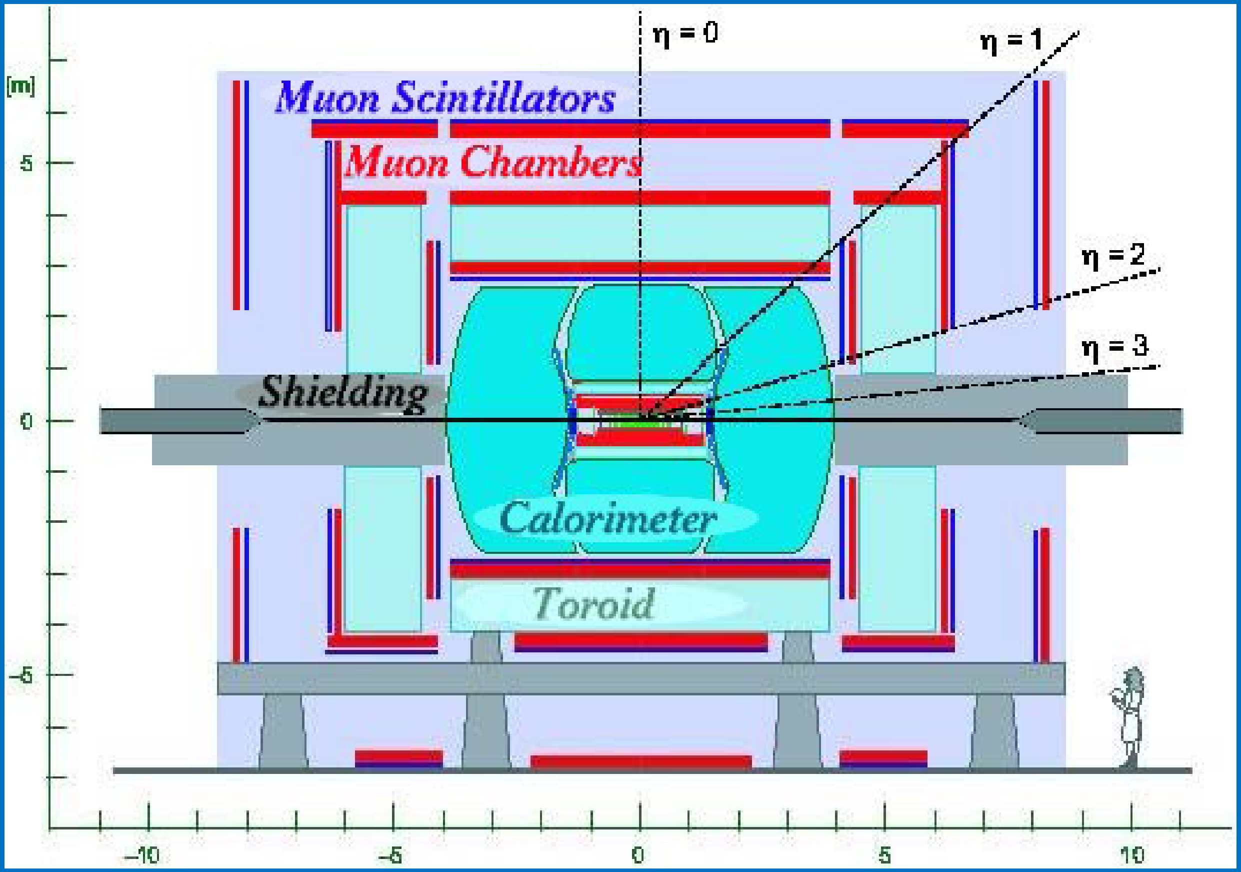
•The electroweak penguin can break the isospin symmetry

•*But then extra sources of CP violating phase would be required in the penguin*

In general the most important components of a general purpose detector system, for B physics, is:

- tracking.
- muon [+electron] id
- triggering: B hadrons comprise is $\mathcal{O}(10^{-3})$ of all events.

  Charmless decay modes have branching fractions $\mathcal{O}(10^{-6})$

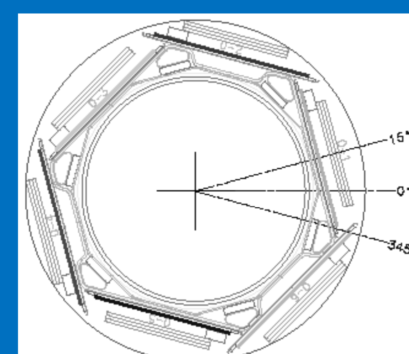


The D0 Silicon tracker…..

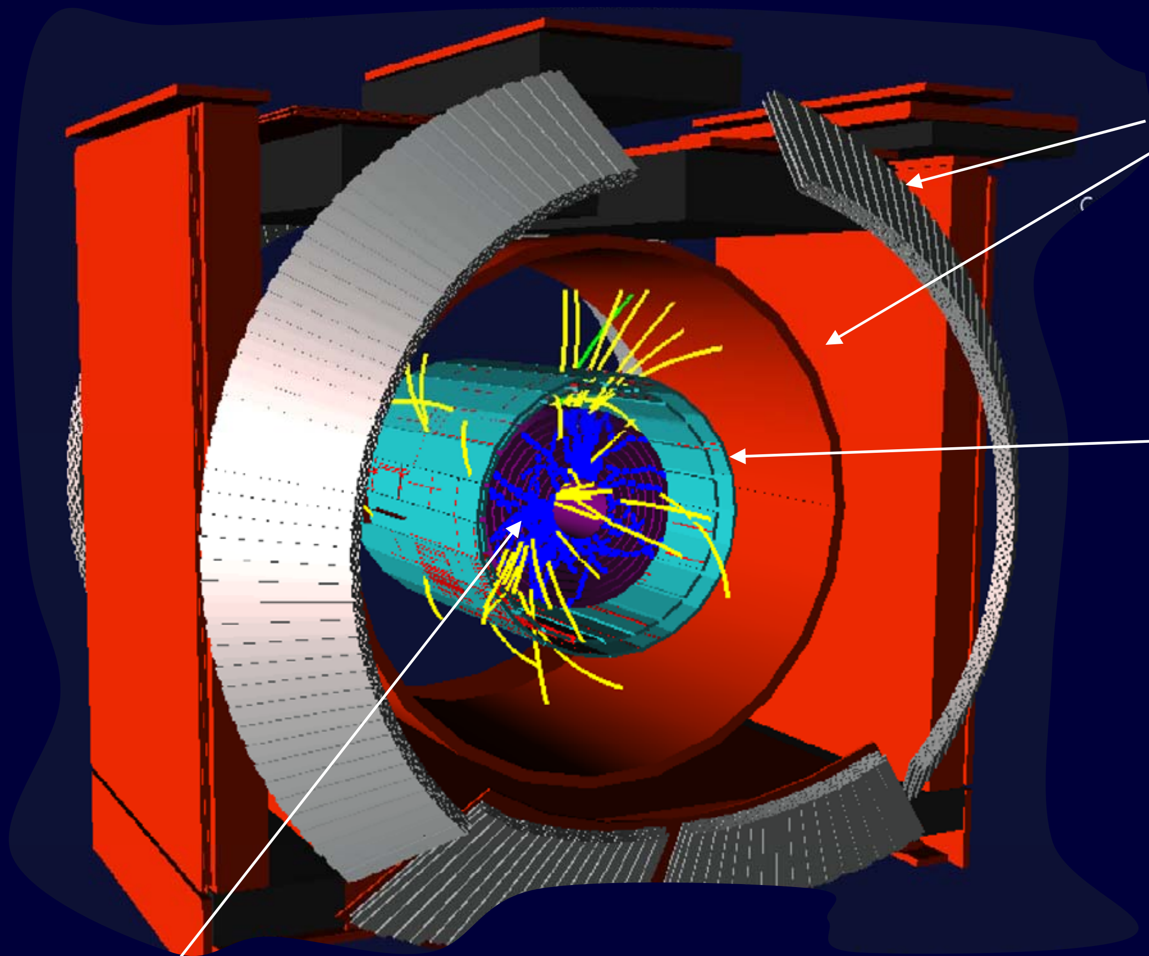
• surrounded by a fibre tracker at a distance 19.5 cm < r <51.5 cm

• now augmented by a high-precision inner layer ("Layer 0")

- 71 (81) μm strip pitch →
- factor two improvement in impact parameter resolution



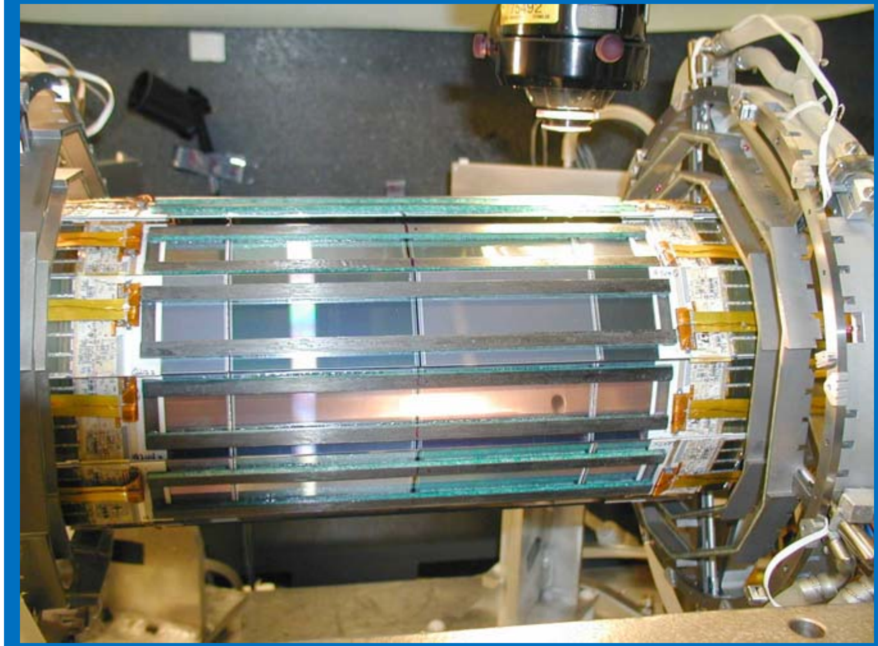
CDF Detector showing as seen by the B physics group.

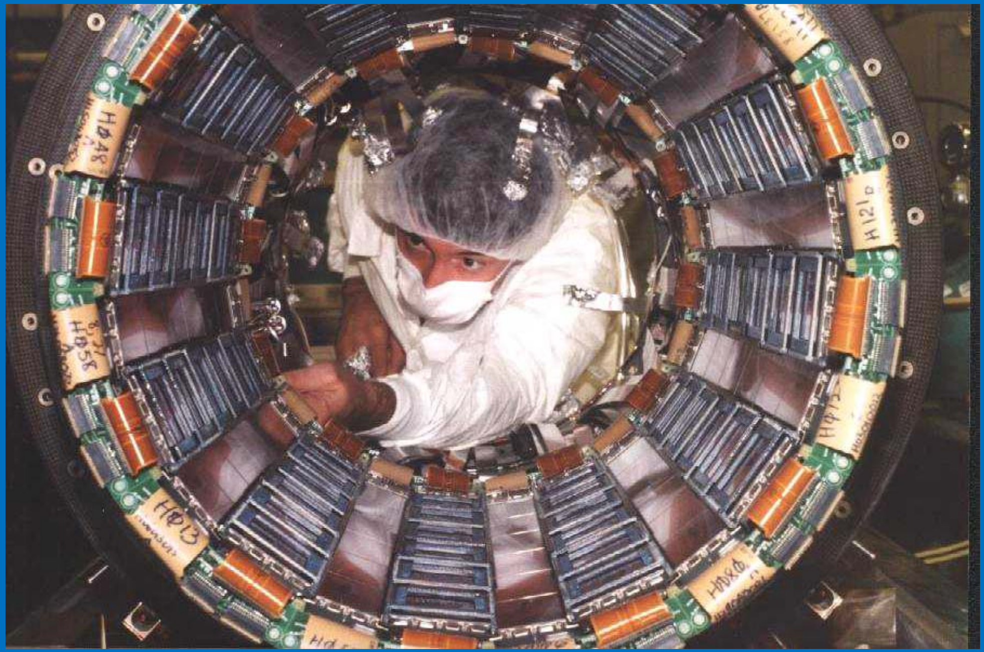


Muon chambers for triggering on the $J/\psi \rightarrow \mu^+\mu^-$ and μ Identification.

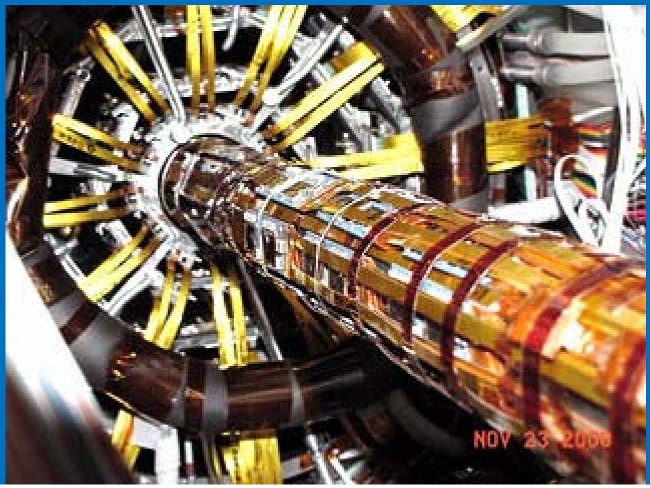
Strip chambers, calorimeter for electron ID

Central outer tracker
dE/dX and TOF system for particle ID
r < 132 cm B = 1.4 T for momentum resolution.





L00: 1.6 cm from the beam.
50 μm strip pitch
Low mass, low M-S.



Uses precise impact parameter information at trigger level 2, to collect hadronic decays of b-hadrons.

The extent to which these features show up depends upon numerical values of the constants governing mixing, decay, direct CP violation and CP asymmetries:

Species	$x=\Delta m/\Gamma$	$y=\Delta\Gamma/\Gamma$	Striking feature
K^0	0.474	0.997	Width difference
B^0	0.77	<0.01	CP violation
B^0_s	27	0.15	Fast Oscillation
D^0	□0.01	□0.01	None

The B^0_s system is characterized by the following standard model expectations:

- Very fast oscillation frequency.
- Small but observable (~10%) lifetime difference.
- Very small CP violation in the standard model.

Contrast this phenomenology with that of B^0 mesons.

$$\left|B^0\right\rangle = \left|\bar{b}\,d\right\rangle$$
$$\left|\bar{B}^0\right\rangle = \left|b\bar{d}\right\rangle$$

Slow oscillation $\Delta m_d = 0.507 \pm 0.005\ \mathrm{ps}^{-1}$

➔ Oscillation length cT = 3.7 mm

Large Standard Model CP violation

$$\beta = -Arg\left(\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$
$$\sin(2\beta) = 0.668 \pm 0.028$$

$$\left|B^0{}_s\right\rangle = \left|\bar{b}\,s\right\rangle$$
$$\left|\bar{B}^0{}_s\right\rangle = \left|b\bar{s}\right\rangle$$

Fast oscillation $\Delta m_s \sim 18\ \mathrm{ps}^{-1}$

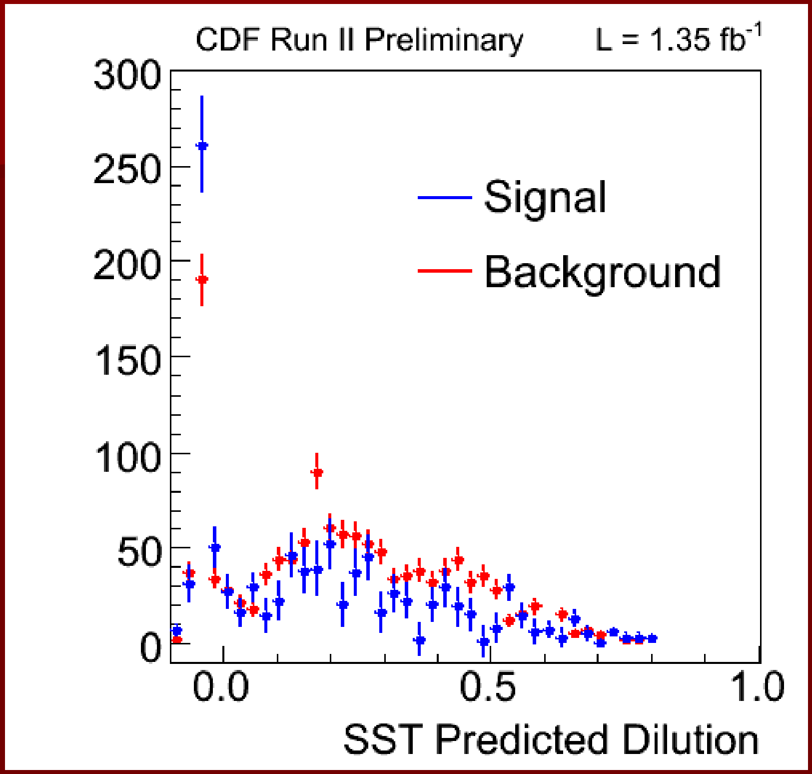
Oscillation length cT = 110 μm

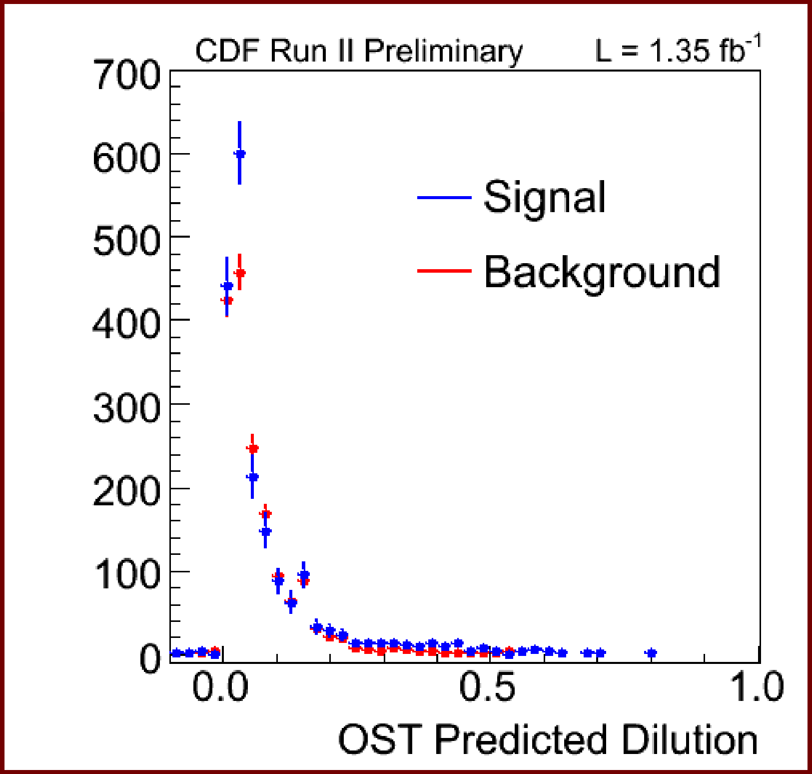
Zero Standard Model CP violation (almost)

$$\beta_s = -Arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$
$$\sin(2\beta_s) = 0.037 \pm 0.002$$

http://utfit.roma1.infn.it/

Tagger performance in $J/\psi\ \phi$ decays:





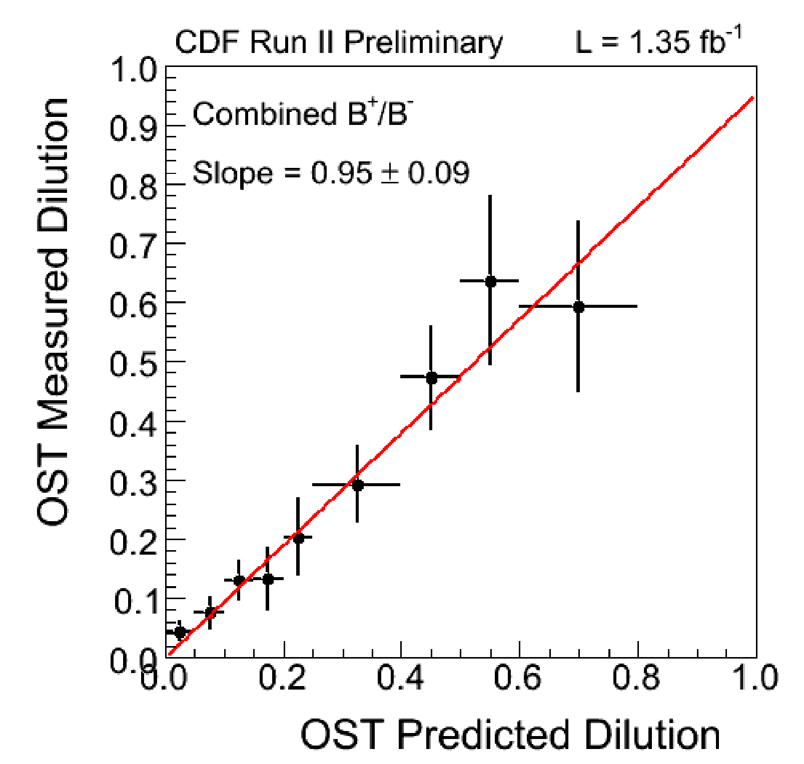
Dilution: (27±4)%
Efficiency: (50±1)%

Dilution: (11±2)%
Efficiency: (96±1)%

The quality of the Prediction of dilution Can be checked against the data:

We reconstruct a sample Of $B^{\pm}$ decays in which one knows the sign of the B meson.

We then "predict" the sign of the meson and plot the predicted dilution vs the actual dilution.



Separately for B^+ and B^-

Scale (from lepton SVT this sample; take the difference B^+/B^- as an uncertainty).