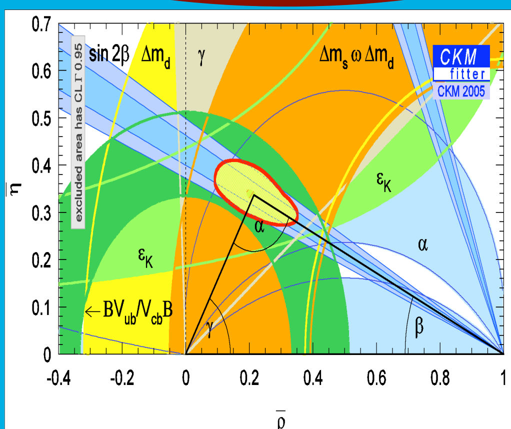
CP violation in the Standard Model

✓ Only source of CP violation in the SM: complex phase in the CKM matrix

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

✓ but "not enough" to explain baryon - anti-baryon asymmetry

To probe CP violation deeper, check CKM matrix unitarity by over-constraining the Unitarity Triangle



Neutral B meson mixing

✓ occurs via 2nd order weak diagrams

✓ 2 eigenstates of definite mass and width: H(eavy) and L(ight)

✓ extract V_{td}, V_{ts} and (more precisely) the ratio V_{td}/V_{ts}:

- $\Delta M_{s(d)} = M^H - M^L \sim |V_{ts(d)}|^2$
- $\Delta\Gamma = \Gamma^H - \Gamma^L$ $\quad \frac{\Delta\Gamma}{\Delta M} = -3.7^{+1.5}_{-0.8} \times 10^{-3}$

$$P(B \to \bar{B}) = \frac{1}{2} e^{-\Gamma t}\left[\cosh(\Delta\Gamma t/2) - \cos(\Delta M t)\right]$$

✓ ΔM sets the frequency of the flavor oscillations

Measuring ΔM_s

Necessary ingredients:

✓flavor at decay [consider flavor specific decays $D_s^-\pi^+$, $D_s^- l^+ \nu X$, …]

✓proper decay time

✓flavor at production, i.e. "tagging":

- ε = tagger efficiency
- D = tagger dilution = 1 – 2w [w is the wrong tag probability]

$\Delta M_d = 0.510 \pm 0.005\ ps^{-1}$ → small → easy to resolve oscillations

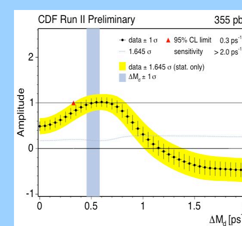
$\Delta M_s > 14.4\ ps^{-1}$ @95% C.L. → large → use AMPLITUDE SCAN meth

1) $$\text{Asymmetry}(t) = \frac{N^{unmixed} - N^{mixed}}{N^{tagged}} = A\,D\cos(\Delta M_s t)$$

2) Scan:

$A \sim 1 \rightarrow \Delta M_s = \Delta M_s^{real}$

$A \sim 0$ otherwise

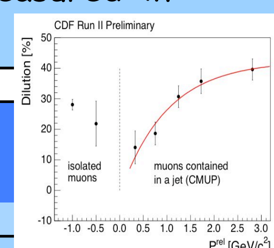


3) Signal significance

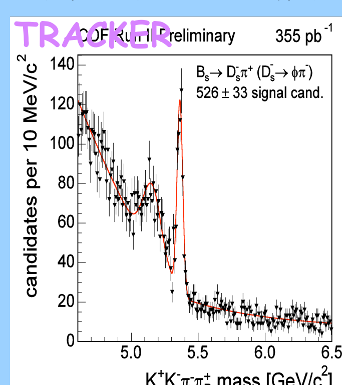
$$\frac{A}{\sigma_A} = \sqrt{\frac{\varepsilon D^2}{2} S \frac{S}{S+B}}\, e^{-\frac{\Delta M_s^2 \sigma_{ct}^2}{2}}$$

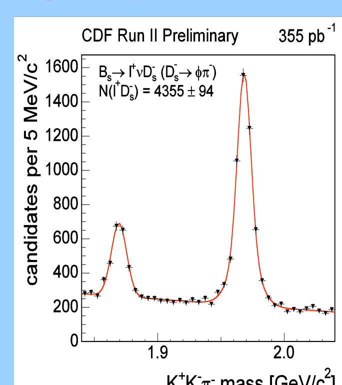
✓ εD^2: tagger dilutions measured in data

Tagger	ε	D	εD^2
Soft Muon	5%	36%	0.56%
Soft Electron	4%	30%	0.29%
Jet Charge	75%	8%	0.58%
Total	84%	---	1.43%

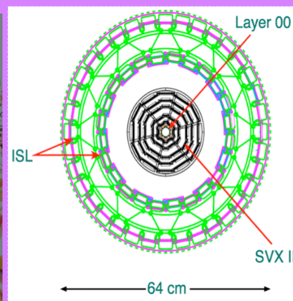


✓ S, S/(S+B) and σ_{ct} -- reasonable values achieved with SILICON TRACKER



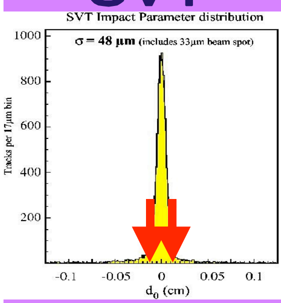


Silicon Tracker



L00+SVXII+ISL: 7-8 silicon layers * * 722K channels * rφ and rz views * 1.3cm < r < 28cm

SVT



ONLINE track processor that uses SVX information to select tracks with large impact parameter w.r.t. the beam line -- a signature of B and D meson decays

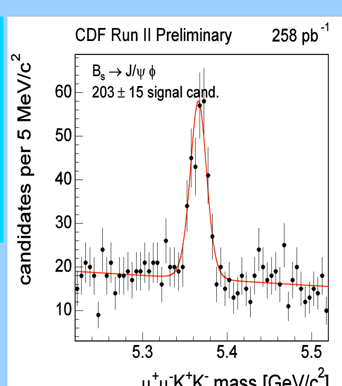
Measuring $\Delta\Gamma_s$

✓ A larger ΔM_s is more difficult to measure, but a larger $\Delta\Gamma_s$ is easier to measure

$\Delta\Gamma_s$ is an insurance we have if ΔM_s turns out to be too large ($\Delta\Gamma \sim \Delta M$)

✓ H and L eigenstates are nearly CP eigenstates → measuring the lifetime in a B_s decay to a CP final state ≡ measuring the lifetime of the corresponding H and L eigenstate

$B_s \to J/\psi\phi$ is P → VV decay
J = 0, S = 0,1,2 → L = 0,1,2
i.e. S, P, and D partial waves:
S,D-waves B_s^L ⇔
P-wave ⇔ B_s^H

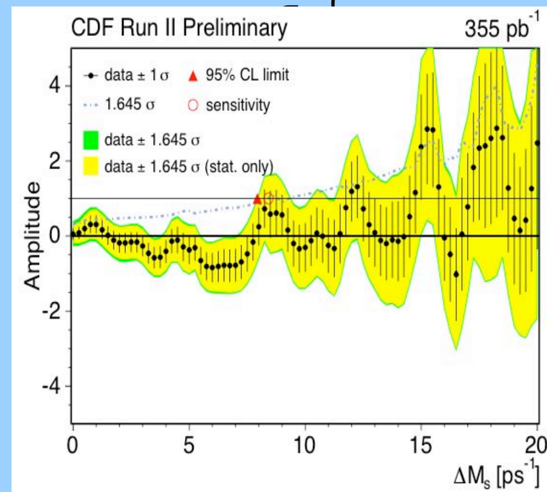


✓ Angular analysis → isolates P-wave from S- and D-waves → separates H and L eigenstates

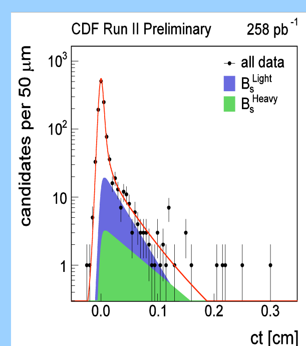
✓ Extract distinct lifetime for each → $\Delta\Gamma_s$ meas

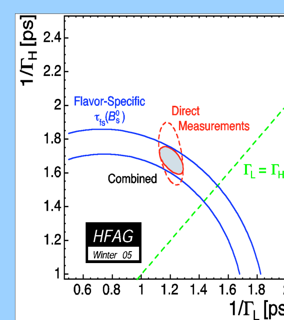
Results

Extract ΔM_s from 2 independent samples: $B_s \to D_s l\nu X$ [larger S] and $B_s \to D_s\pi$ [better σ]



Combined result: $\Delta M_s > 7.9$ ps^{-1} @95% C.L. Sensitivity: 8.4 ps^{-1}





$\Delta\Gamma_s / \Gamma_s = -0.65^{+0.33}_{-0.25}$ $\Delta\Gamma_s = -0.47^{+0.24}_{-0.19}$

✓Statistical uncertainties dominate the measurements

✓ Large B_s samples are used as checks/calibrations

Coming Improvements

ΔM_s:

✓ include Same-Side K Tagging (using new TOF system) → double tagging power

✓ "event by event" primary vertex reconstruction → improve σ_{ct}

✓ additional channels and trigger paths → larger S

✓ more statistics

$\Delta\Gamma_s$:

✓ alternative approaches [$Br(B_s \to D_s^{(*)-} D_s^{(*)+})$, lifetime in CP-even dominated samples]

✓ more statistics