Tevatron results

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Outline

- Overall comparison on Tevatron and 4S/5S environments
- Cover selected B_s physics results from DØ and CDF
  - Try and point out where measurements can be improved with 5S data (or complement 4S data)
- Topics:
  - B_s lifetime
  - $\Delta\Gamma/\phi_s$
  - Rare decays

Tevatron versus Belle

	Belle	Tevatron
Goal	Dedicated B program	Main purpose is high p_T
trigger	Inclusive	μ, or displaced vertex (semi-inclusive)
Hadronic backgrounds	~3:1 ~all B's written to tape	Enormous, very small fraction of produced B's written to tape
PID	Excellent $K/\pi/\mu/e$	Excellent μ, OK K/π, poor e, for e from B
neutrals	Excellent γ, π^0, η	~none from B
Boost	~0.5 parallel to silicon, known apriori	~1-2 perpendicular to silicon (sensitivity to Δm_s), unknown apriori
B_s production	Coherent, no tagging	Incoherent, tagging OK

If you can do it, you can do it better at Belle

Still many interesting things you can only do now at the Tevatron

Tevatron versus Belle

B-factory numbers approximated for 250 fb^{-1}, Tevatron numbers estimated at 1 fb^{-1}

	Belle	CDF	DØ
$B^+ \to J/\psi K^+$	~18k	~18k	~18k
$B_s \to J/\psi \phi$	?	~2k	~2k
$B_s \to D_s (\phi\pi)\pi$	?	~2k	~50
$B_d \to \pi^+\pi^-$	605	882	-
$B_d \to \rho^+\rho^-$	205	-	-
$B_s \to K^+K^-$	?	1473	
$B_s \to \phi\gamma$	18	-	-

Dimuons about same

Tev on top for now

Vertex versus muon trigger

h^+h^- ~same but no π^0s

Tev on top for now

Some things only at 5S

Lifetime Ratios

Sensitive probe of higher order terms in HQE

	Theory*	Data	What we learned
B^+/B_d	1.06 ± 0.02	1.071 ± 0.009	$1/m_b^3$ is important, and can be calculated
Λ_b/B_d	0.90 ± 0.05	0.90 ± 0.03**	Non-perterbative terms important, and lattice is working
B_s/B_d	1.00 ± 0.01	0.94 ± 0.02***	Both $1/m_b^3$ and non-perterbative effects supposed to be small

1: Franco et al hep-ph/0203089
2: PDG07 + new DØ
3: HFAG07 (not recent CDF)

Statistics or something else?

B_s Lifetime

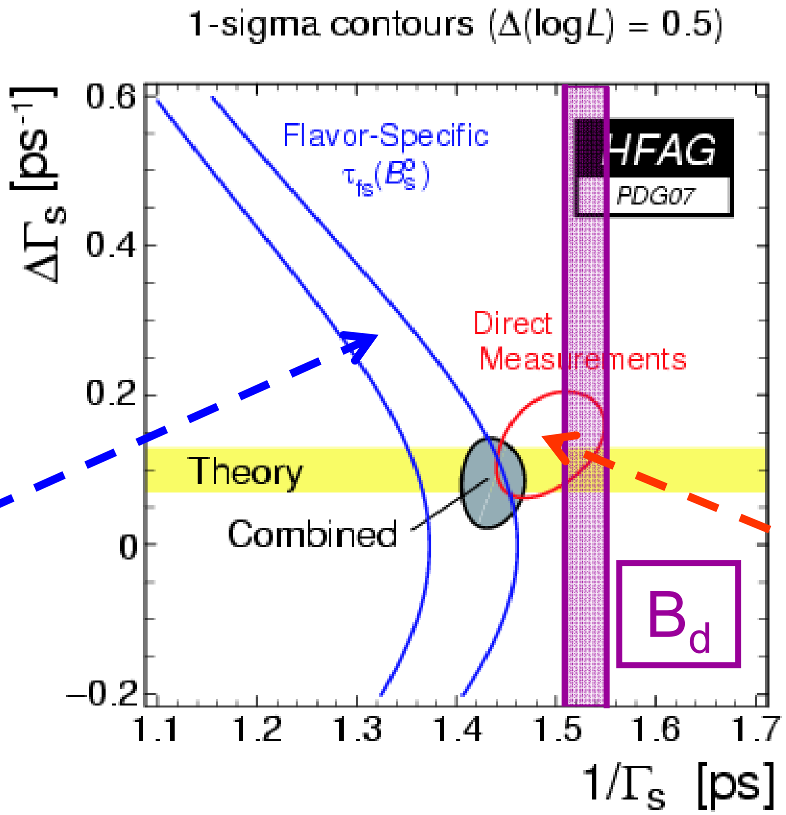
Complicated by sizeable $\Delta\Gamma = \Gamma_H - \Gamma_L$

Flavor specific

1-D lifetime fit to $D_s l\nu$, $D_s\pi$…

$$\tau_{FS} = \frac{1}{\Gamma_s}\left(\frac{1+y^2}{1-y^2}\right)$$

$$y = \frac{\Delta\Gamma}{2\Gamma}$$



Direct

Simultaneous fit to lifetime and polarization in $J/\psi\ \phi$

$$\Gamma = \frac{1}{2}\left(\Gamma_L + \Gamma_H\right)$$

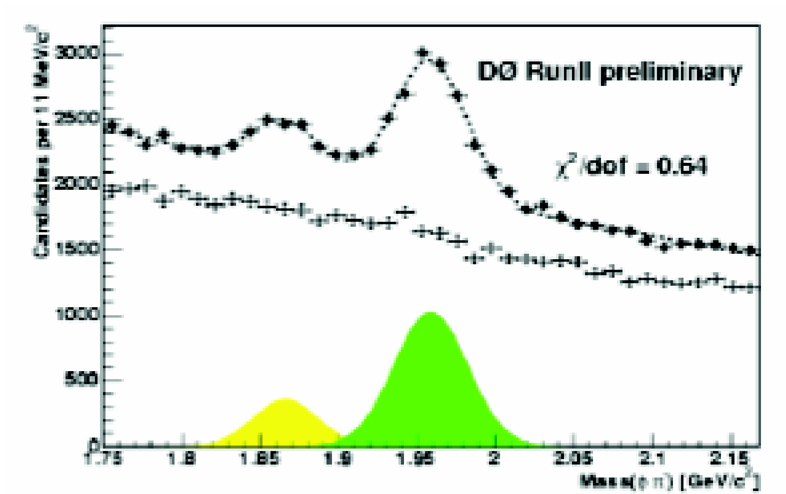
$$\Delta\Gamma = \Gamma_L - \Gamma_H$$

40% reduction in error including FS

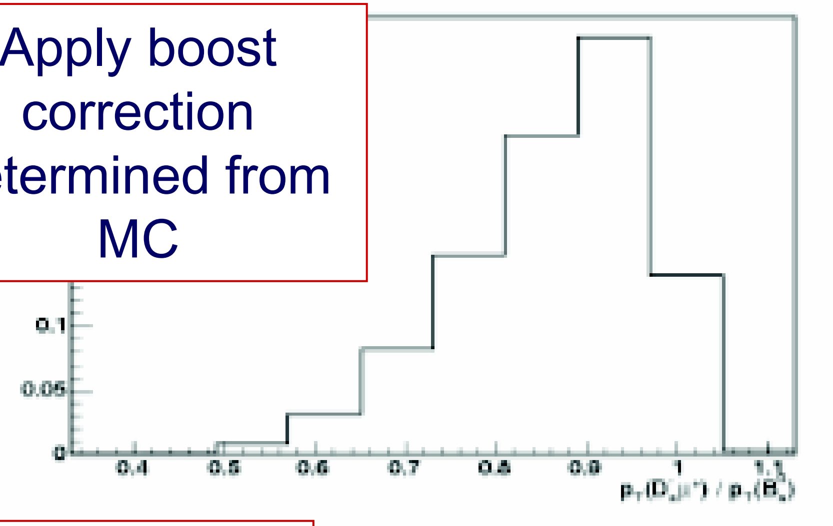
But also drives discrepancy with B_d

Semileptonic B_s lifetime

Reconstruct signal as D_s correlated with muon



Apply boost correction determined from MC

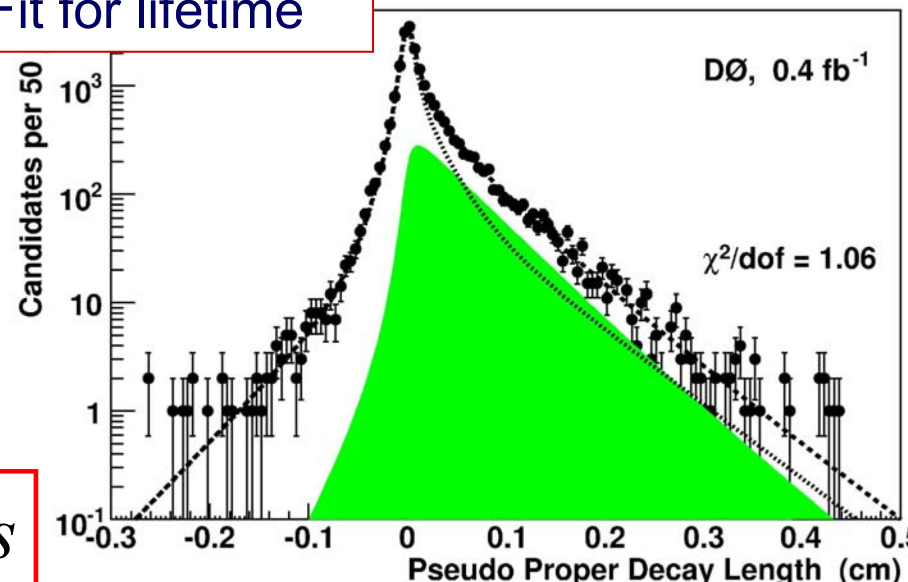


~90% signal,

~10% peaking backgrounds:

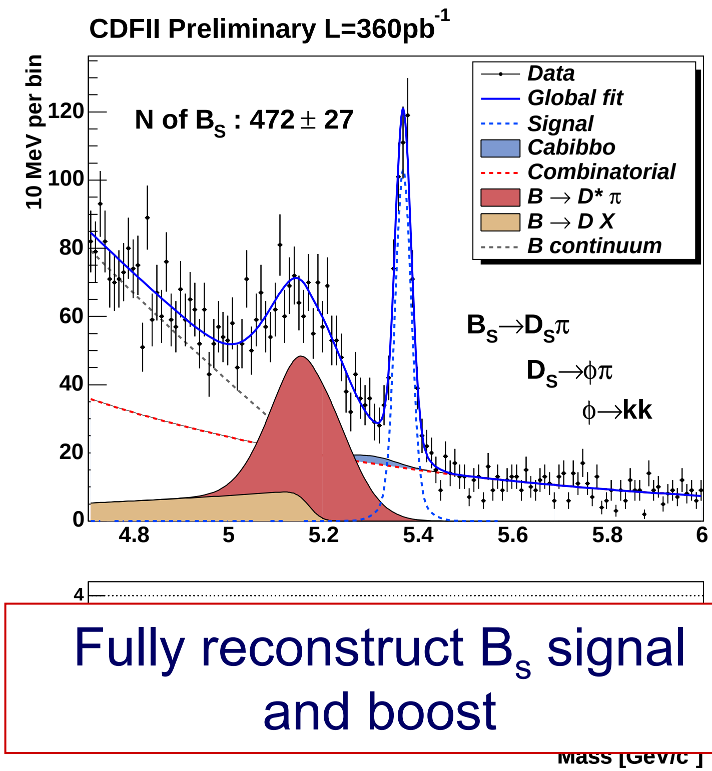
B→DsD, direct DsD

Fit for lifetime

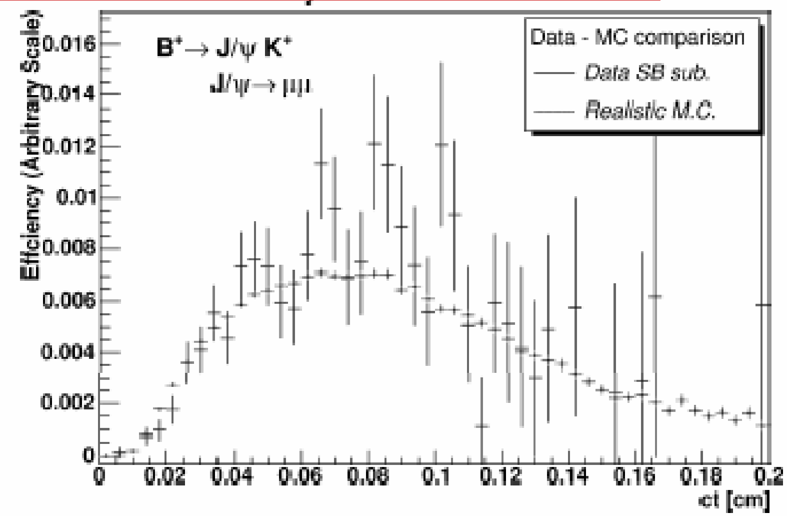


$$\tau_{FS}(B_s) = 1.398 \pm 0.044^{+0.028}_{-0.025}\ ps$$

Hadronic B_s lifetime



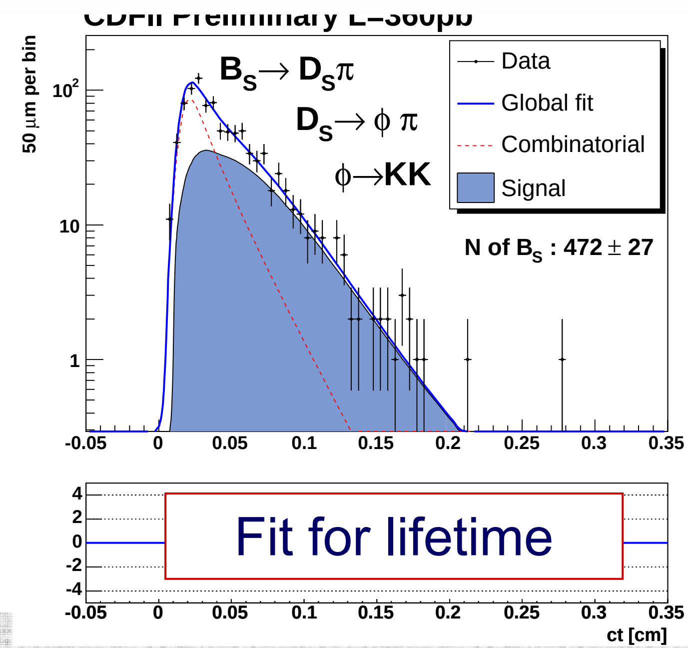
Correct for trigger efficiency



Fully reconstruct B_s signal and boost

No background or boost issues, but need precise trigger model

$$\tau_{FS}(B_s) = 1.60 \pm 0.10 \pm 0.02\, ps$$



Fit for lifetime

Lifetime results

Cross checks with B_d lifetime in the same topologies:

DØ/world = 1.01 ± 0.06

CDF/world = 0.99 ± 0.02

World average ~2.5 σ below Bd lifetime

B_s lifetime at the 5S

- Less uncertainty associated with high statistics semileptonic modes
  - known boost
  - background samples from 4S
- Tevatron:
  - Hadronic results still stat limited
  - semileptonic can move to direct lifetime ratio measurement to reduce sys.
  - Both cases: Not far from sys. limited
- If there is a B_s lifetime problem, it needs to be confirmed in a b-factory environment
- we will always want a good B_s lifetime measurement independent of $J/\psi\ \phi$

Bs mixing parameters

$$\left|g^{\pm}(t)\right|^2 = \frac{e^{-\Gamma t}}{2}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) \pm \cos(\Delta m t)\right]$$

$$\Delta m = m_H - m_L = 2\left|m_{12}\right|$$

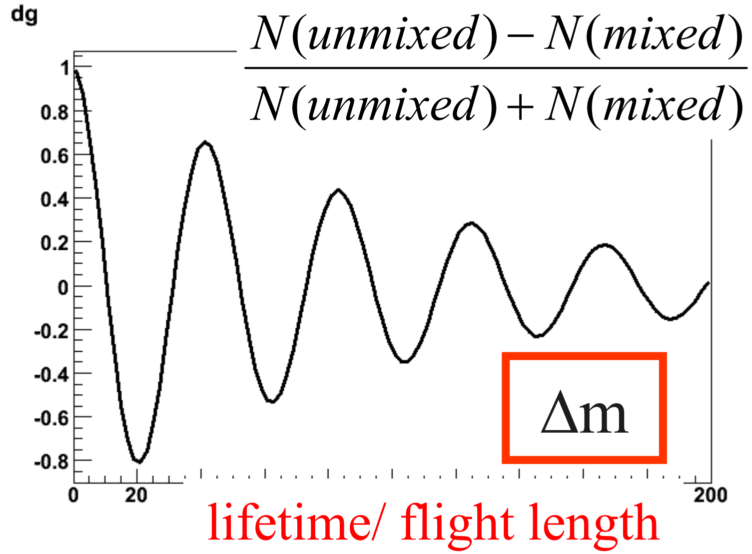
$$\Delta\Gamma = \Gamma_L - \Gamma_H = 2\left|\Gamma_{12}\right|\cos\phi$$

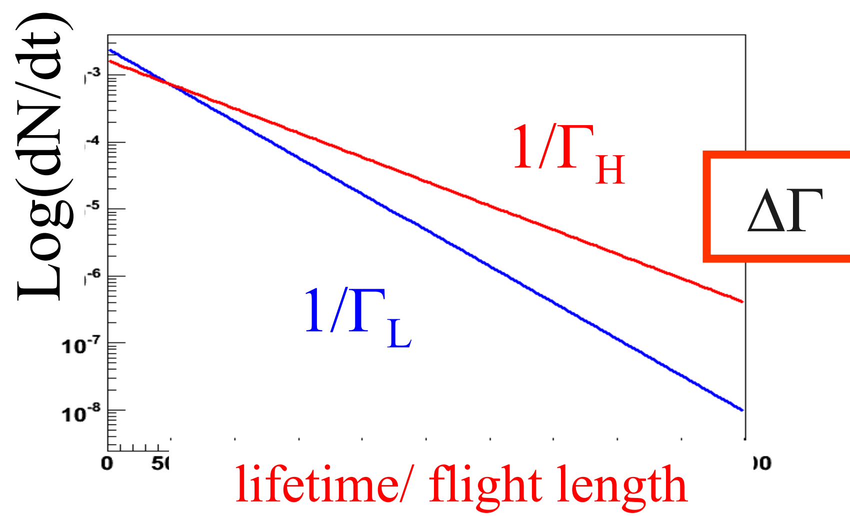
$$\phi = \arg\left(-\frac{m_{12}}{\Gamma_{12}}\right)$$

$$\Gamma(M \Rightarrow \overline{M}) \neq \Gamma(\overline{M} \Rightarrow M)$$

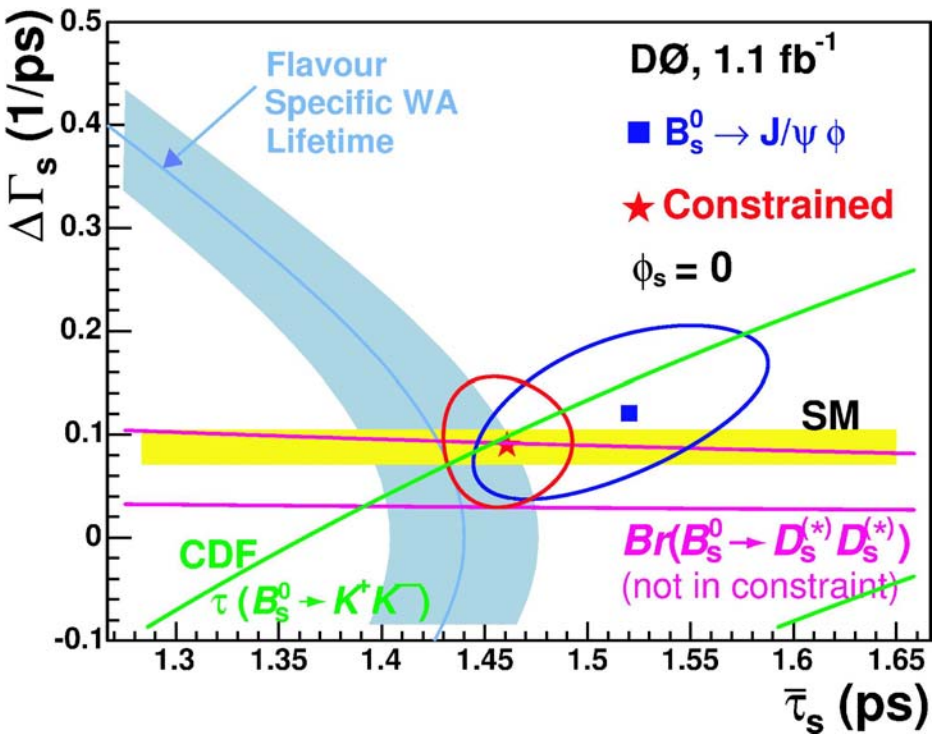
$$\left|\begin{matrix} even \\ odd \end{matrix}\right\rangle \neq \left|\begin{matrix} light \\ heavy \end{matrix}\right\rangle$$

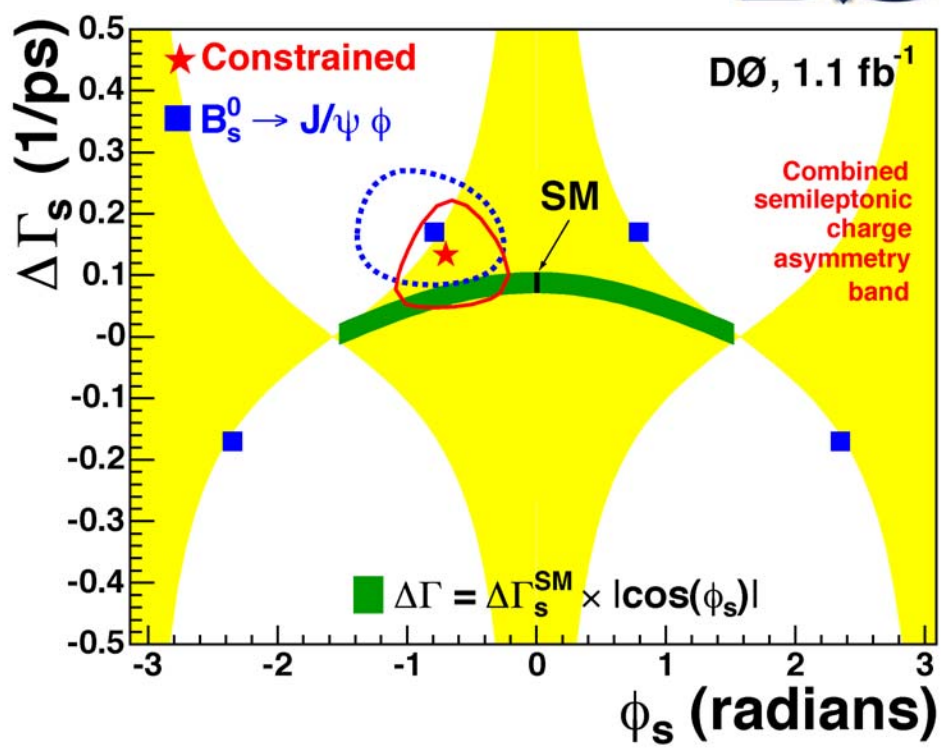
φ





$\Delta\Gamma$ and CPV in the B_s system



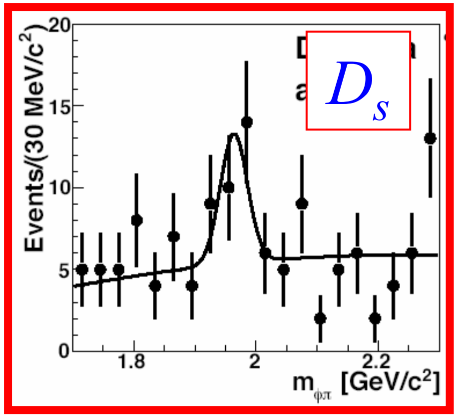


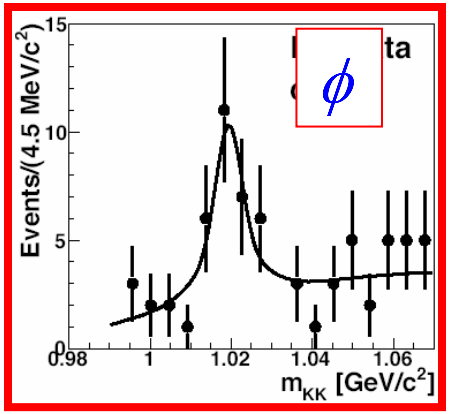
- all measurements are untagged (or time-integrated)
  - Sensitivity to CPV in untagged samples if $\Delta\Gamma \neq 0$
- Everything is $\Delta\Gamma$ x $f(\phi_s)$
  - Theory prediction for $\Delta\Gamma$ very important
    - **Cant be trusted without $\tau(B_s)/\tau(B_d)$**
- $D_s^{(*)} D_s^{(*)}$ theory errors uncontrolled
  - Best $\Delta\Gamma$ measurement but not used in constraint

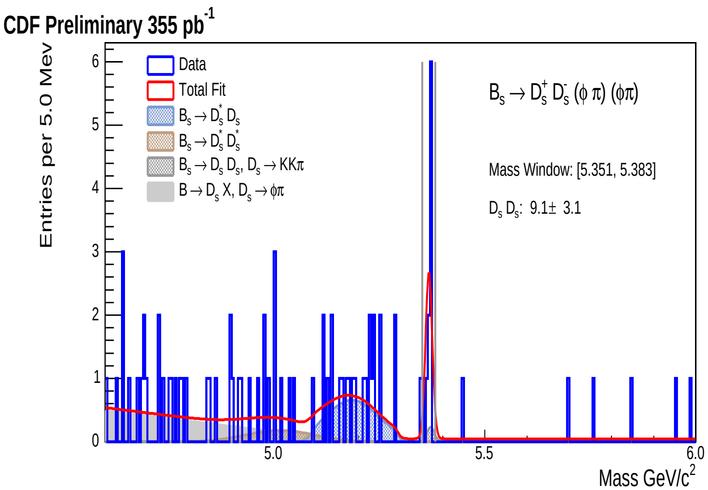
$\Delta\Gamma$ and $D^{(*)}_s D^{(*)}_s$

Measured through correlated production of $D_s \to \phi\pi$ and $D_s \to \phi\mu\nu$

Or fully reconstructed channels







$$BF(B_s \to D_s^{(*)} D_s^{(*)}) = 0.039^{+0.019}_{-0.017}{}^{+0.016}_{-0.015}$$

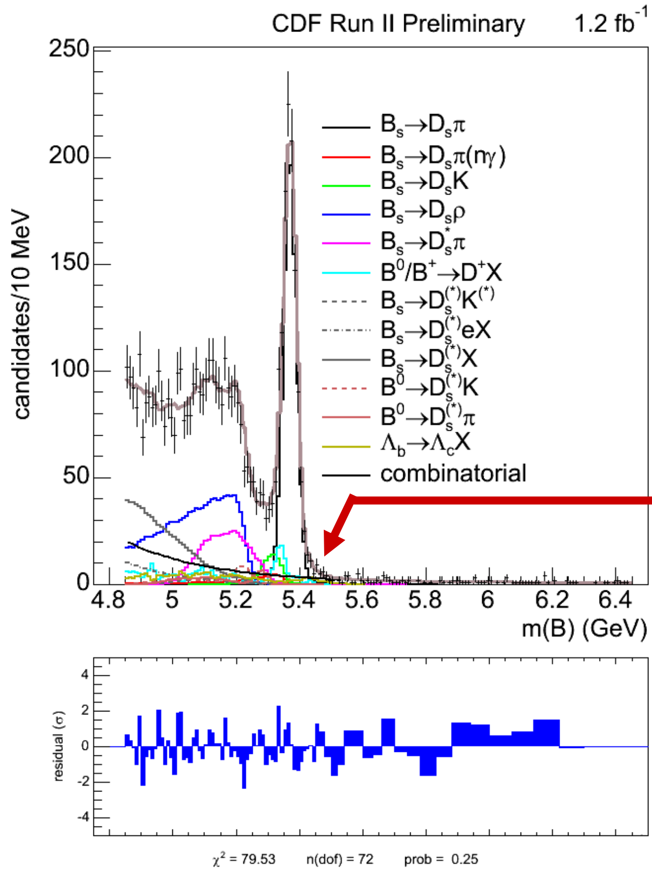
$$\frac{\Delta\Gamma_{CP}}{\Gamma} = 0.079^{+0.038}_{-0.035}{}^{+0.031}_{-0.030}$$

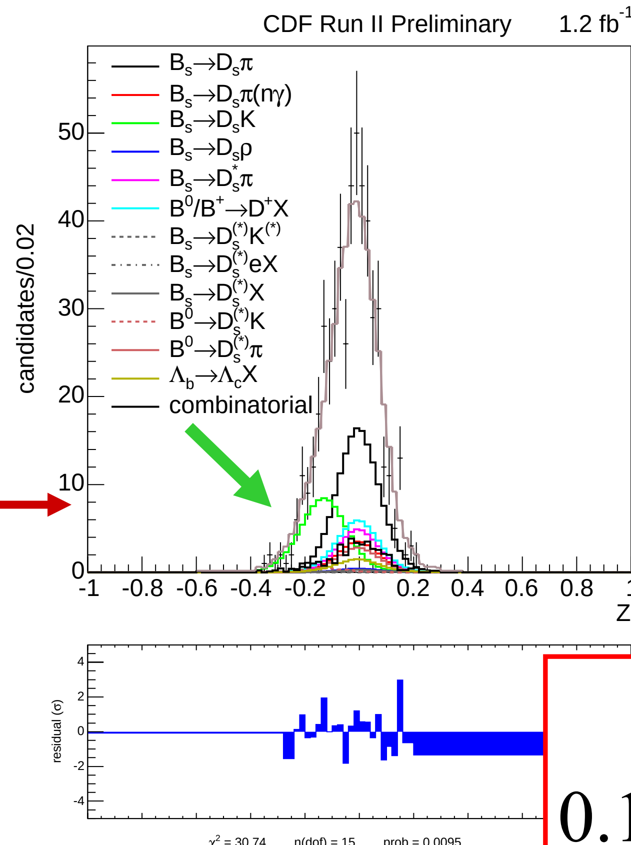
Partial reconstruction more complicated but gives direct access to $\Delta\Gamma_{CP}$

ΔΓ and D_s K

Recently proposed by to use lifetime measurement in D_sK to determine sign of strong phases for J/ψ ϕ and remove 2-fold ambiguity

(Nandi, Nierste hep-arXiv:0801.0143)





PID variable based on dE/dx and momentum asymmetry

109±19 D_sK events

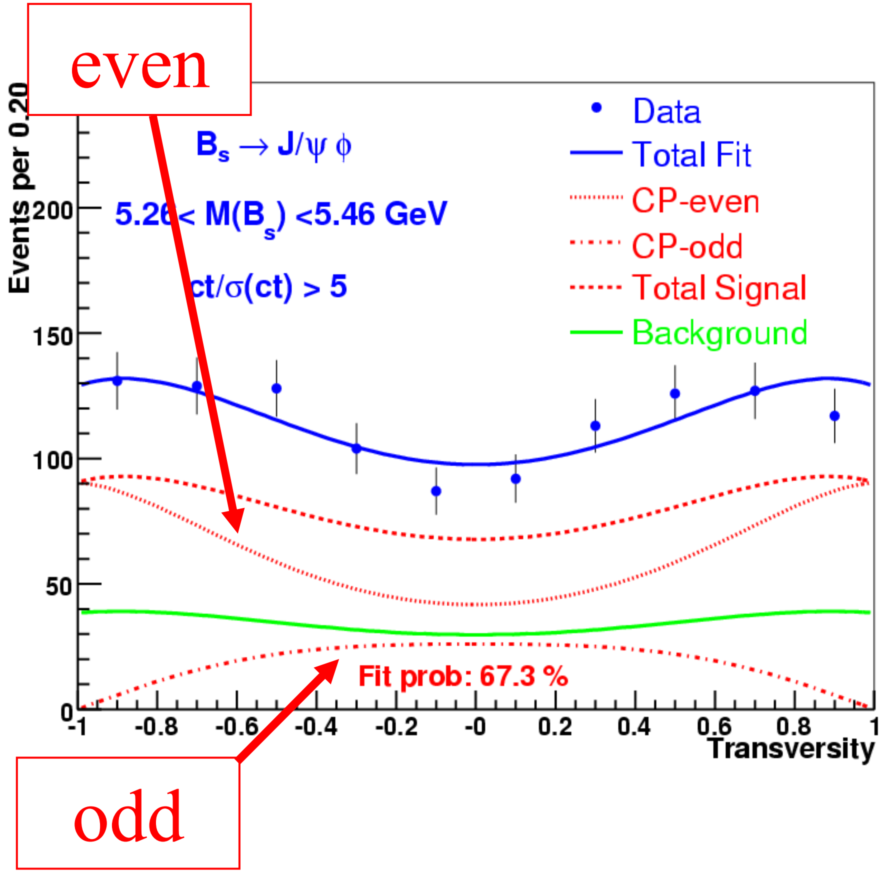
~8 σ significance

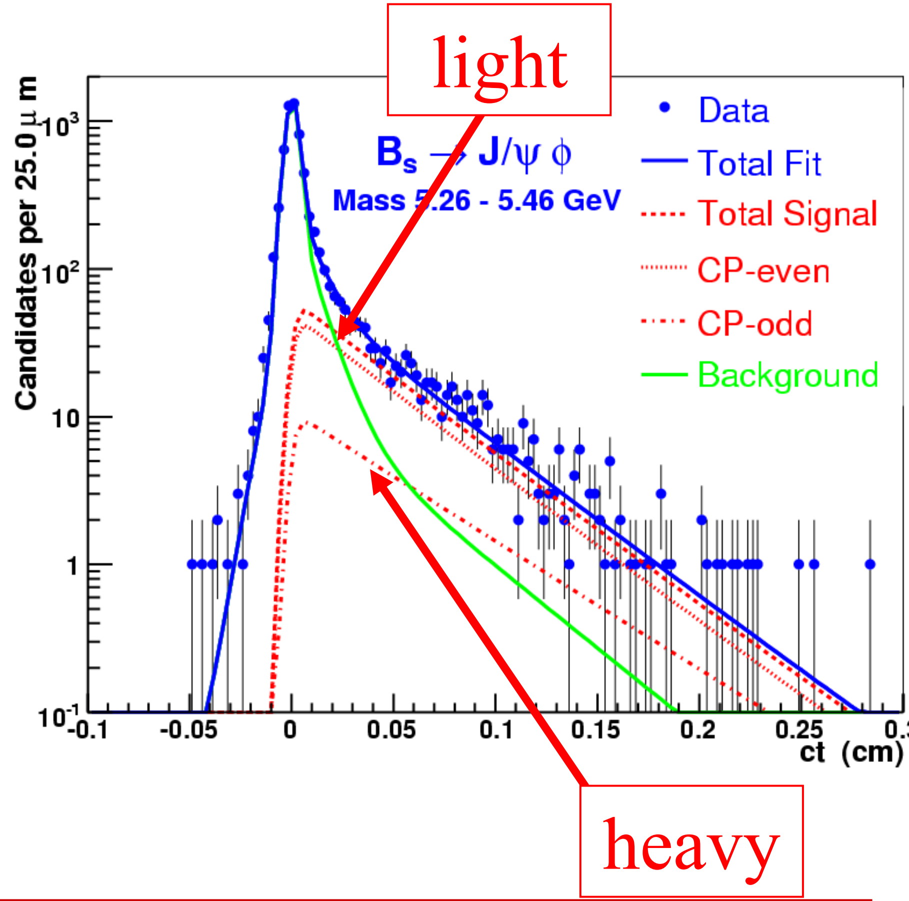
$$D_sK / D_s\pi = 0.107 \pm 0.019 \pm 0.008$$

ΔΓ and Untagged J/ψ ϕ

Polarization tells if you are looking at an even or odd Bs

Lifetime tells you if you are looking at a B long or a B short

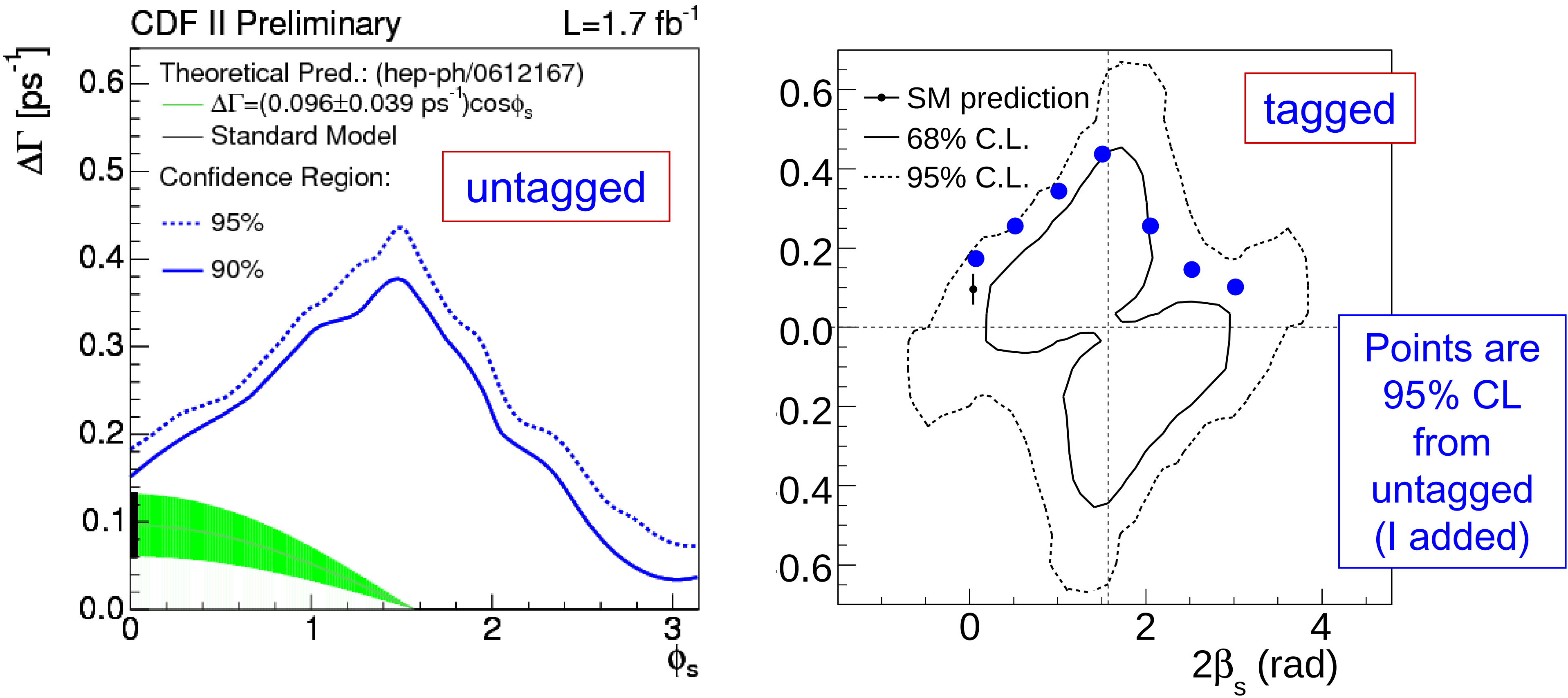




Comparing the two (plus interference terms) allows CPV measurement

Tagged versus untagged

Adding tagging where available increases sensitivity (but $\varepsilon D^2 \sim 5\%$)



More importantly, extra terms partially reduce 4 fold ambiguity to 2 fold ambiguity

$\Delta\Gamma/\phi_s$ at the 5S

- Tevatron: 10 publications on $\Delta\Gamma$ and ϕ_s so far, only 1 includes time dependent tagging
  - Combined DØ/CDF: tagged/untagged $J/\psi\ \phi$, $A_{S,}$, τ_{FS} will be interesting

- If ϕ_s is large:
  - Decreasing ambiguities more important than tagging
  - $BF(D_s^{(*)}D_s^{(*)})$, $\tau(D_sK)$

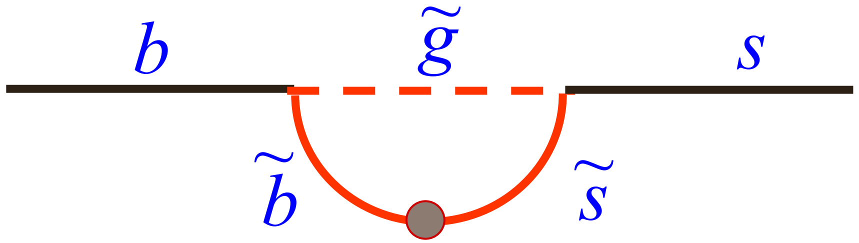
- If ϕ_s is large:
  - Tevatron + Belle can discover new physics before LHC
    - At least we need a tie breaker for choosing conventions

- If ϕ_s is small:
  - Precision τ and $\Delta\Gamma$ measurements will help guide theory and extraction of ϕ_s at LHCb

New Physics and Rare decays

$b \to s$: Once everyone's best guess for new physics

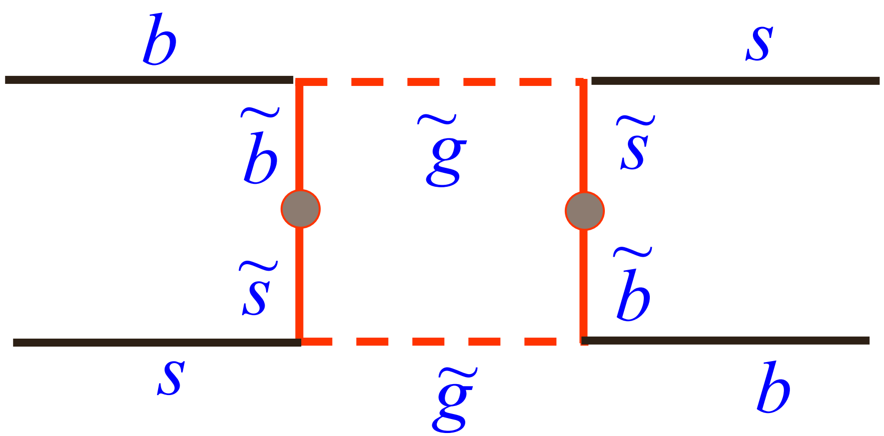
$\Delta B = \Delta s = 1$



$b \to s\,\gamma$:

too small to measure

$\Delta B = \Delta s = 2$



Δm_s:

too small to measure

New Physics and rare decays

$b \to s$: Still everyone's best guess for new physics.

But now need to look where we have a chance to see small effects

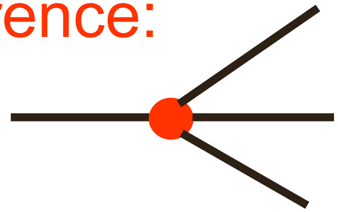
CPV phases:

$\Delta B = \Delta s = 1$: $b \to s\bar{s}s$,

$\Delta B = \Delta s = 2$: ϕ_s

Interference:

$b \to s l^+ l^-$



Large SM suppression:

$B_s \to \mu\mu$

$(B^+ \to \tau\nu)$

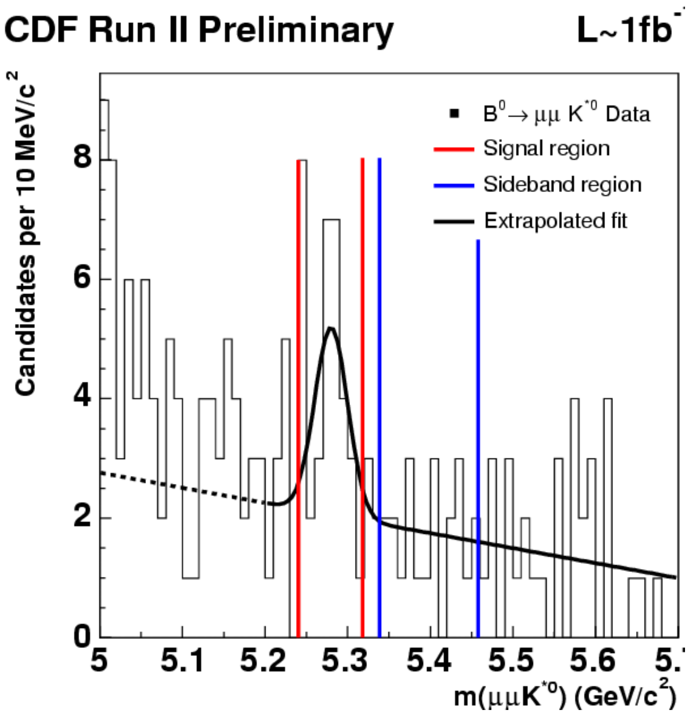
$(K \to \pi\nu\nu)$

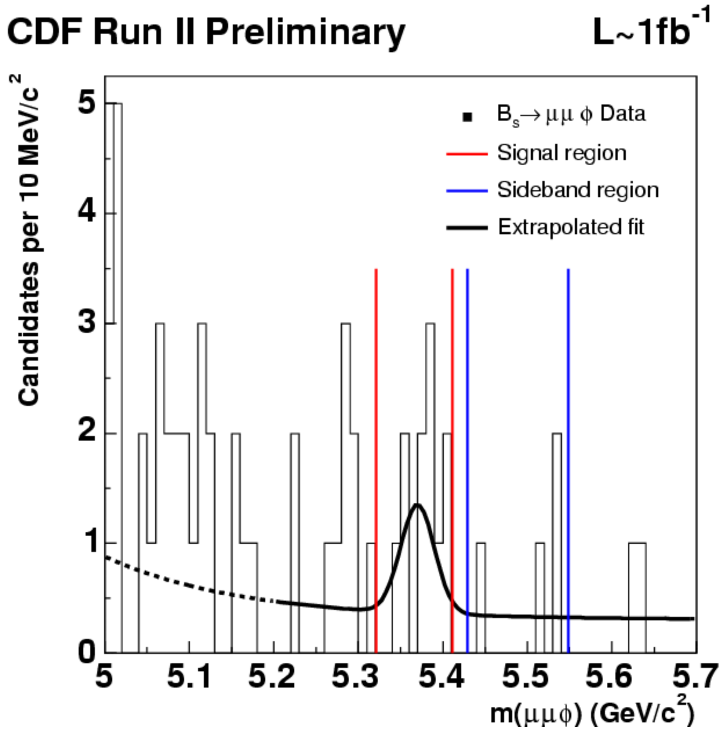
(Closely related to $b \to s$)

Radiative decay: $B \to V\mu\mu$

18.5 ± 6.7 K*

7.5 ± 3.6 ϕ





1 fb^{-1}:

~26 $B \to V\mu\mu$ events

5 fb^{-1}:

~250 events (CDF + DØ)

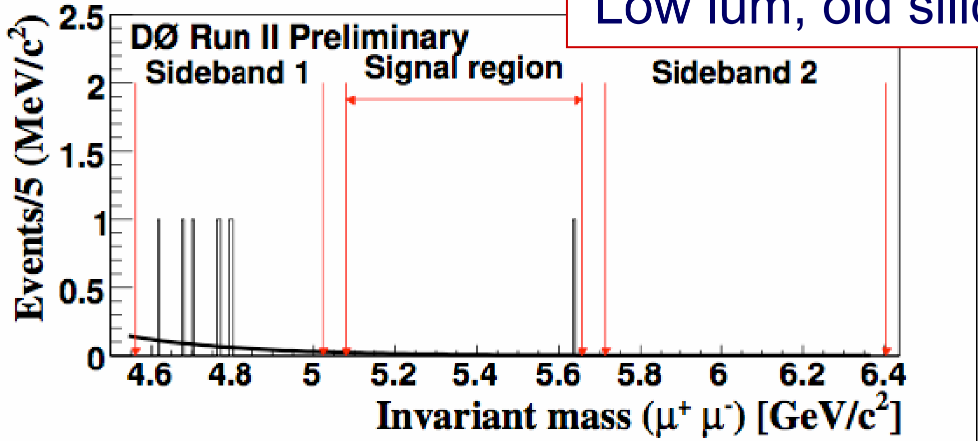
Should add not-trivial stats for world average A_{FB} in next few years

Annihilation: $B_s \to \mu\mu$

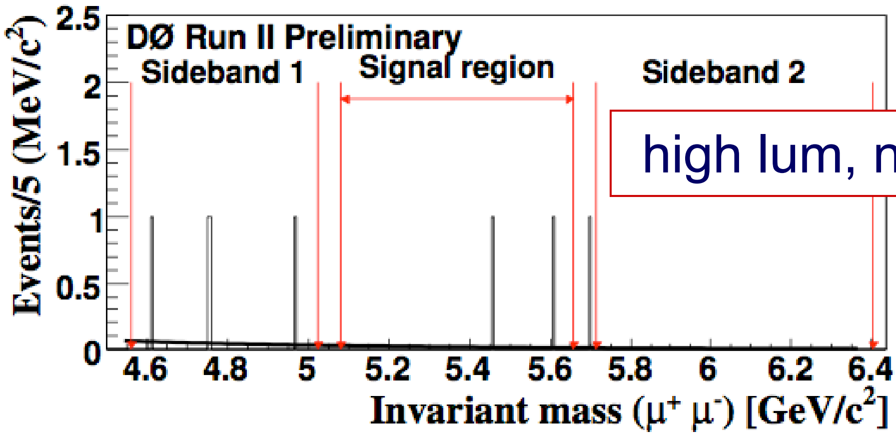
~most important thing we are doing in the Tevatron B program right now

2 fb^{-1} results:

Low lum, old silicon



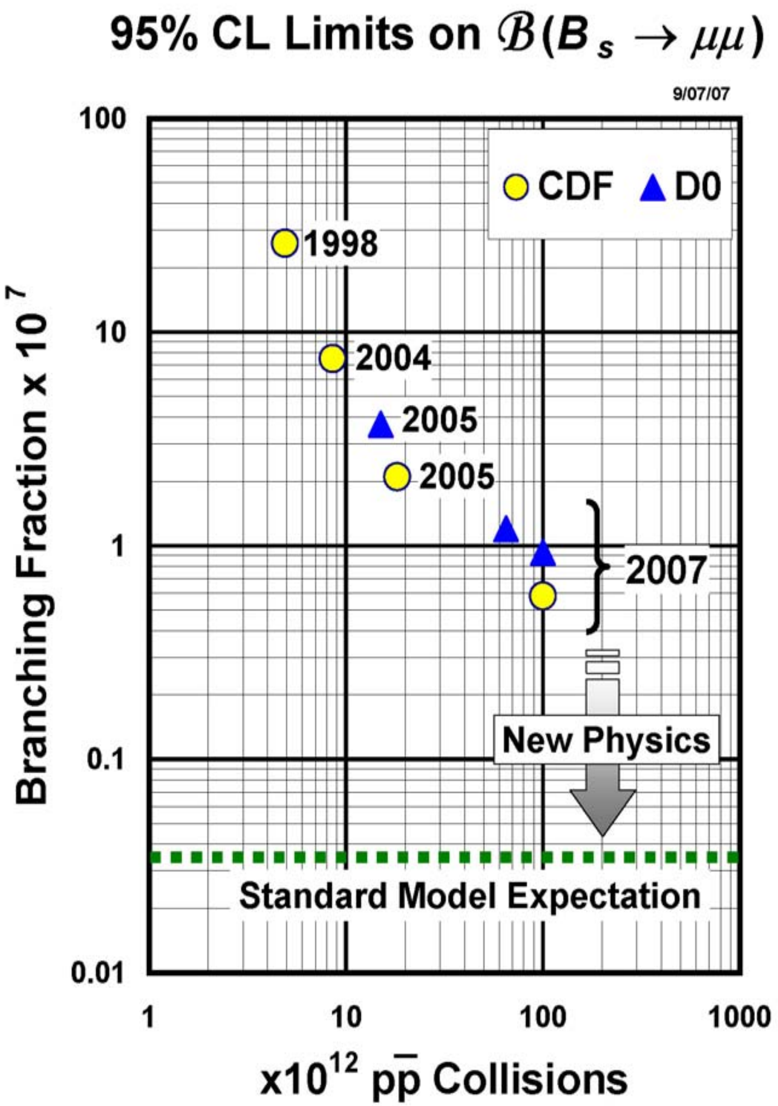
Pretend there is a CDF plot here



high lum, new silicon

$B_s \to \mu\mu$ PAST AND FUTURE

- Step 1 (0.5-1 fb^{-1}):
  - Do we understand $e(\mu\mu)/e(K\mu\mu)$?
    - Not at all trivial since trigger is tight, p_T distributions are different, and B p_T not well known
  - Can we reduce combinatoric background?
- Step 2 (1-2 fb^{-1}):
  - Multivariate background suppression
  - $B \to h^+h^-$ (CDF)
- Step 3 (2-4 fb^{-1}):
  - Smarter pre-selection
  - $B \to h^+h^-$? (CDF and DØ)
  - Fake tracks at high lum (DØ)
  - Specific cuts to remove B background



$B_s \to \mu\mu$ VERSUS $B \to \tau\tau$

- No serious attempt (yet) at $B_s \to \tau\tau$ at Tevatron
- At B factories?
  - BaBar limit uses fully reconstructed B data set → not interesting (4×10^{-3})
  - Can it be done without reconstructing the other B?
    - Look at Belle note 296 for examples of finding back-to-back tau's in hadronic events
  - 4S/5S lum ratio indicates B_d decay just as possible as B_s decay
- If there is a factor of 10 enhancement, Tevatron $\mu\mu$ + B factory $\tau\tau$ would be very interesting

Future flavor at Fermilab

- Many very exciting questions will be difficult to answer at LHC (or at least require very large data sets)
  - How does the higgs couple to fermions?
  - How does TeV scale physics influence flavor?
  - Is there lepton flavor violation at the TeV scale?
  - Leptogenesis?
  - Beyond TeV scale physics?

Future flavor at Fermilab

- ~Current accelerator complex:
  - Low mass higgs → bb at Tevatron
  - NOvA
  - $\mu \rightarrow$ e conversion
- Project X:
  - sensitivity to minimal flavor violation signatures in kaons
  - Next generation $\mu \rightarrow$ e conversion
  - Neutrino CPV
  - Long baseline to DUSEL (proton decay)
  - dedicated fixed target tau/charm

Possibility for a very exciting US accelerator-based program complementing or competing with flavor programs in Asia/Europe

Conclusions

- Many exciting B_s results from Tevatron and more to come
- Results from the 5S can have a very significant impact, particularly on CPV measurements
  - When you think of ϕ_s, think big
- Potential for exciting accelerator based program next decade in US that will complement super B factory and LHC results