B Physics @ the Tevatron

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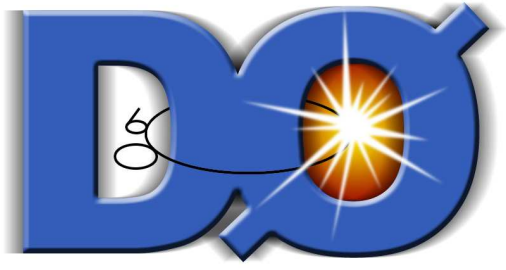
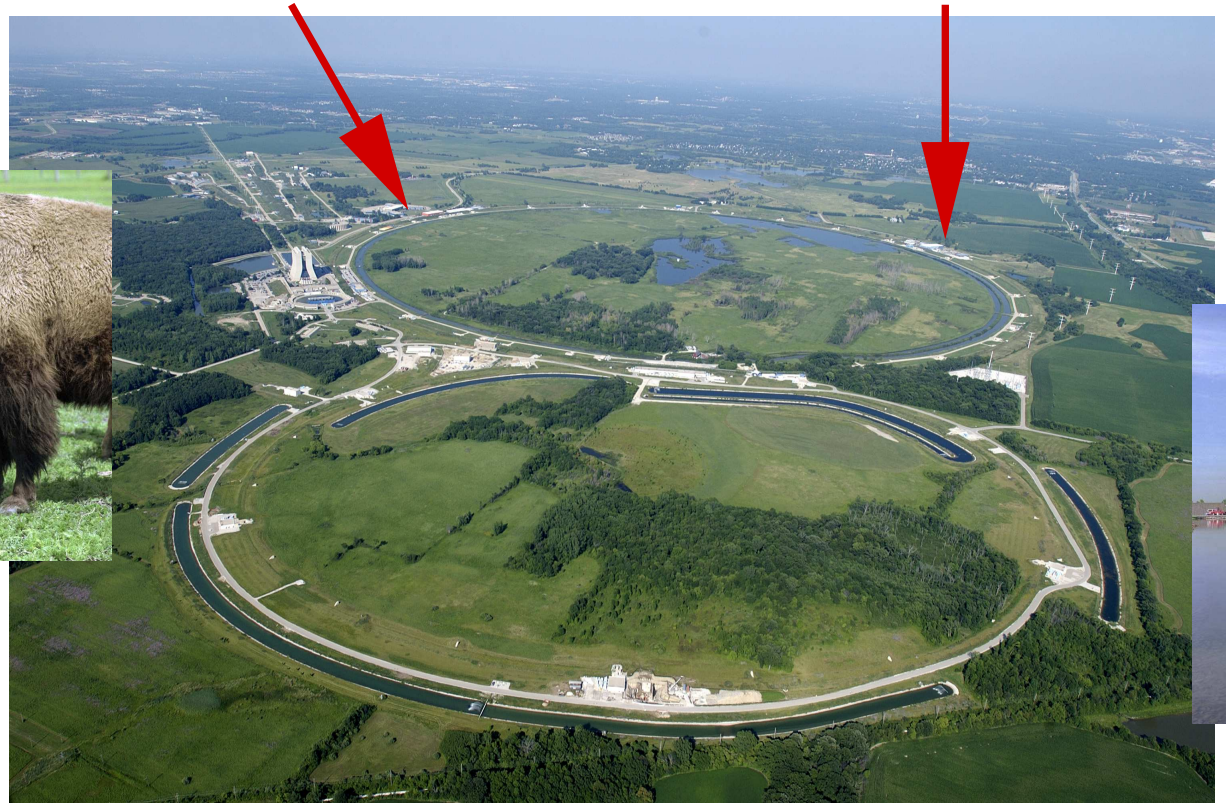
DESY, 9^{th} of November 2007



Tevatron

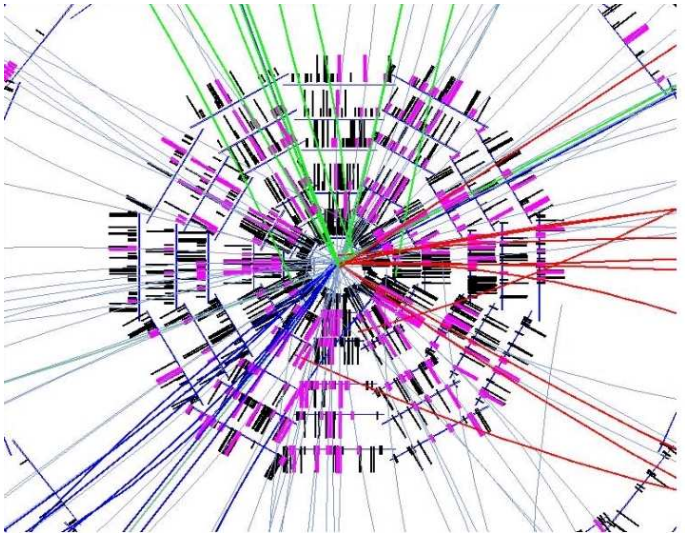


$p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV

observed by two experiments: CDF & D0

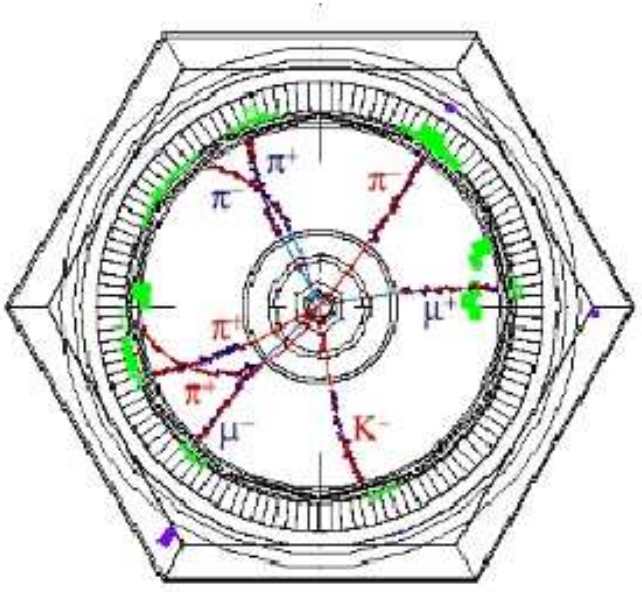
B Physics @ Hadron Colliders

+ Large cross section
  $\sigma(p\bar{p} \to bX) \approx 100\ \mu b$
  $\leftrightarrow$ B factories: $\approx$ 1 nb
+ High center-of-mass energy
+ Heavy & excited B's,
  e.g. B_s, B_c, Λ_b, Ξ_b, B^{**}, B_s^{**}, ...



event @ CDF

- $\sigma(p\bar{p} \to X)$ O(10^3) higher
  $\to$ require excellent trigger
- High track density
  $\to$ require dedicated algorithms



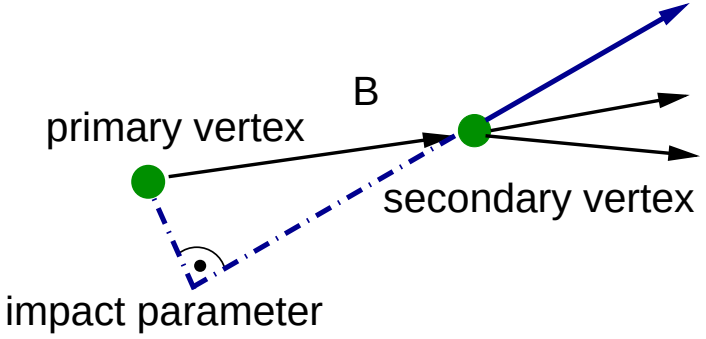
event @ BABAR

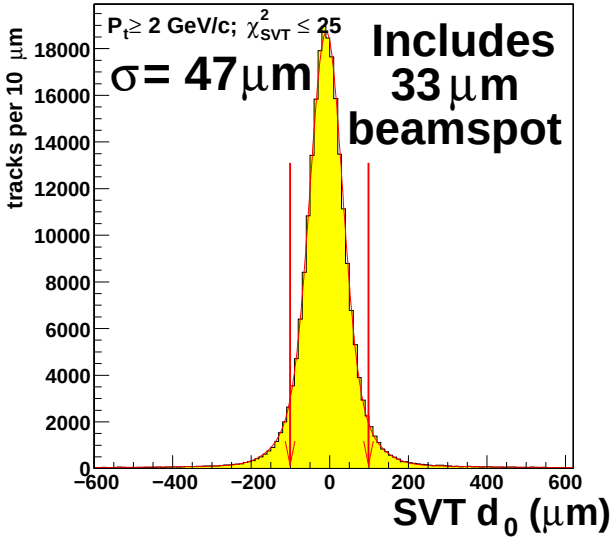
Tevatron unique place to study large amounts of B_s Mesons.

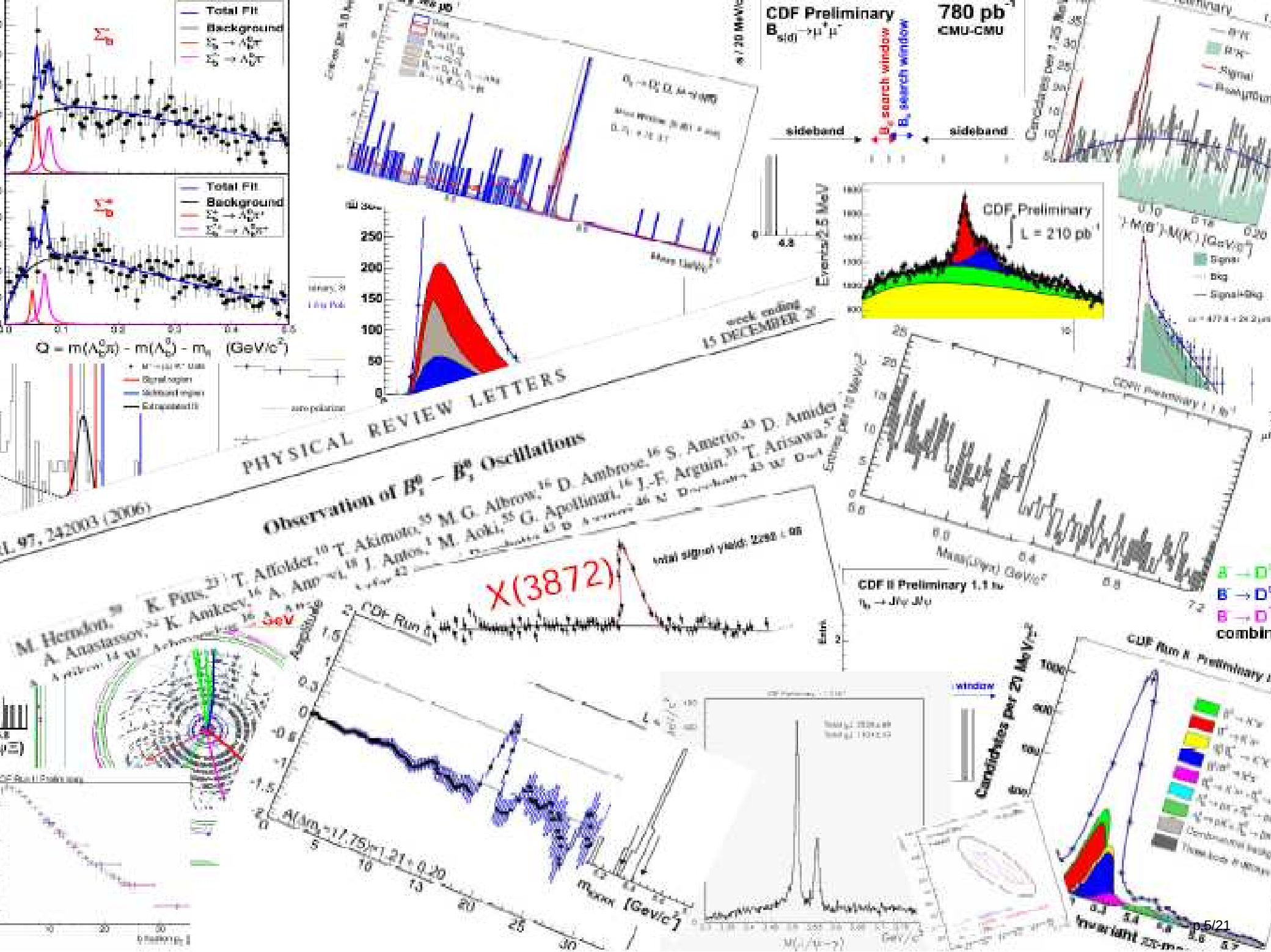
B Triggers

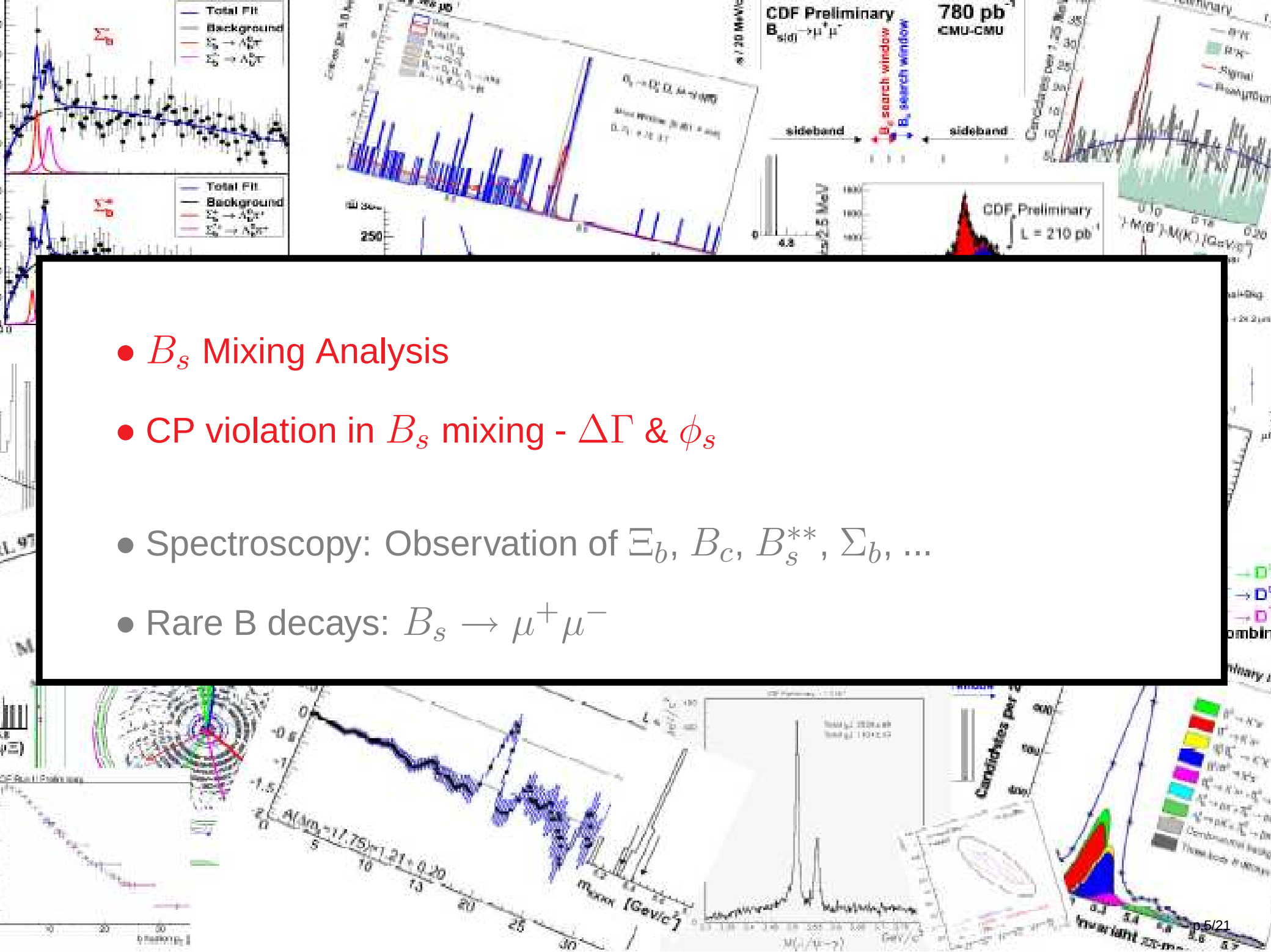
Trigger signatures: lepton (e,μ) and displaced tracks

- $B \to J/\Psi X;\ J/\Psi \to \mu^+\mu^-$ $\Rightarrow$ Di-Muon Trigger (CDF+D0)
  + muon provides easy trigger
  - small branching ratio
- Semi-leptonic B decays $\Rightarrow$ Lepton Trigger (D0)
  + large branching ratios ($\approx$ 20%) + Displaced Track (CDF)
  - missing neutrino
- Fully hadronic B decays $\Rightarrow$ Two Track Trigger (CDF)
  + $\approx$ 80% of branching ratio
  - requires displaced track trigger



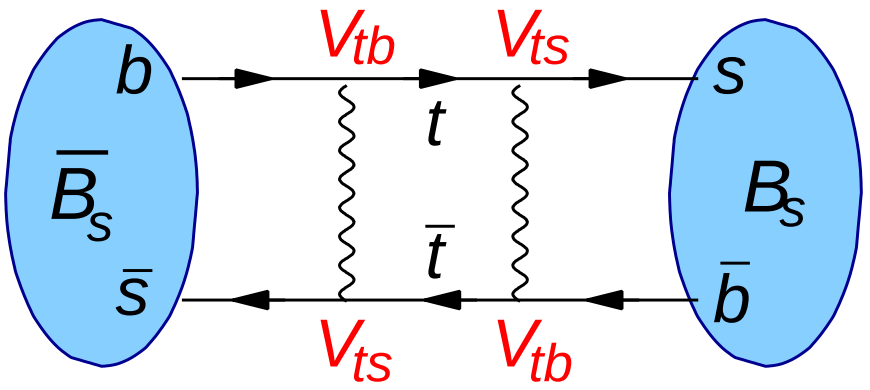



Total Fit
Background
Q = m(Λc0π) - m(Λc0) - mπ (GeV/c2)
CDF Preliminary
780 pb-1
CMU-CMU
sideband
sideband
CDF Preliminary
L = 210 pb-1
PHYSICAL REVIEW LETTERS
week ending
15 DECEMBER 2
Observation of Bs0 – B̄s0 Oscillations
X(3872)
CDF Run II Preliminary 1.1 fb-1
CDF Run II Preliminary



- B_s Mixing Analysis
- CP violation in B_s mixing - $\Delta\Gamma$ & ϕ_s
- Spectroscopy: Observation of Ξ_b, B_c, B_s^{**}, Σ_b, ...
- Rare B decays: $B_s \to \mu^+\mu^-$

B_s Mixing

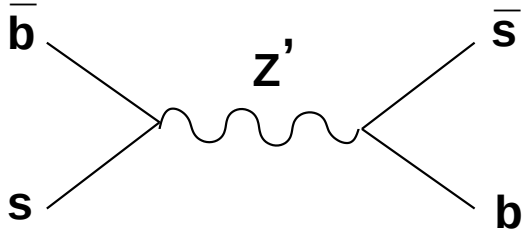


- Access to fundamental SM parameters

$$\Delta m_s = \frac{G_F^2}{6\pi^2}\eta_B m_{B_s}\hat{B}_{B_s} f_{B_s}^2 M_W^2 S(\frac{m_t^2}{m_W^2})|V_{ts}^* V_{tb}|^2$$

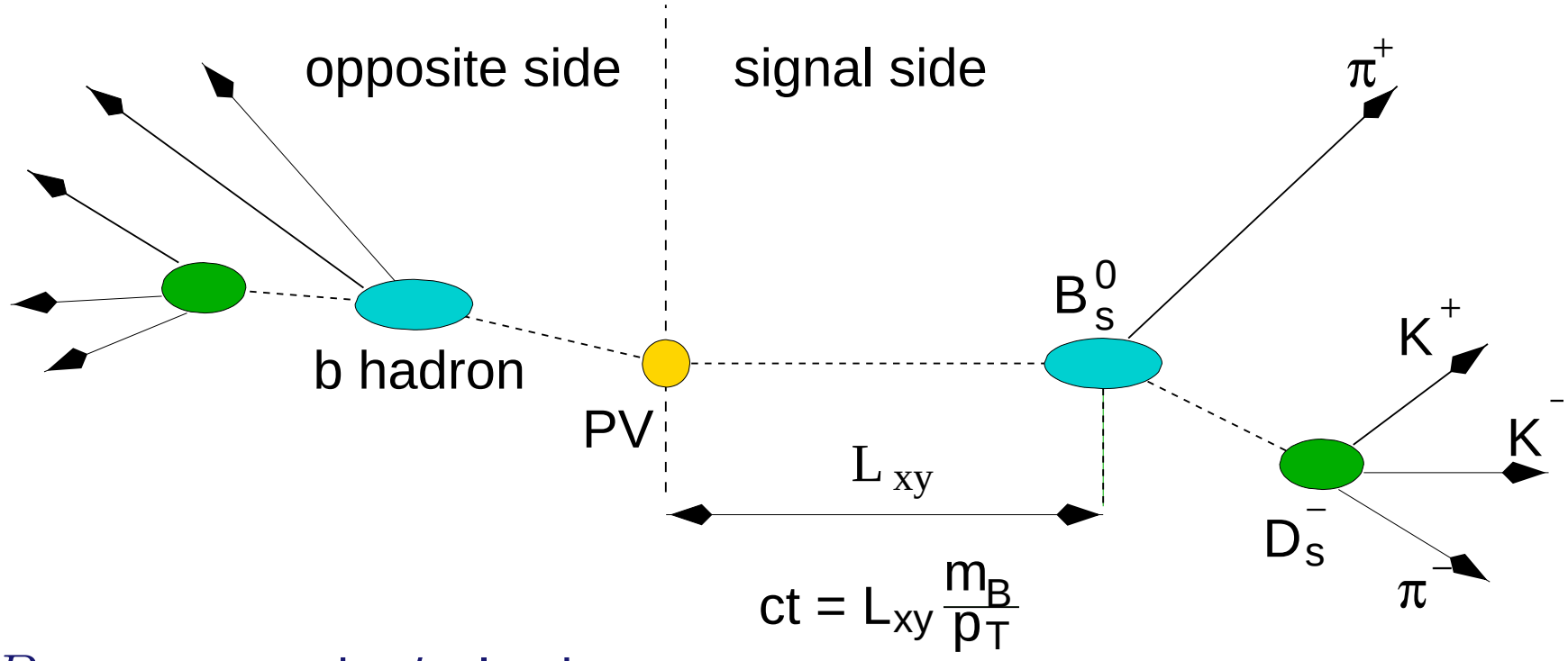
- Hadronic uncertainties are canceling out

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}}\xi^2\frac{|V_{ts}|}{|V_{td}|}$$



- Prerequisite for time dependent CPV
- Possible contributions from “New Physics”

$B_s - \bar{B}_s$ Mixing Analyses



1) B_s reconstruction/selection

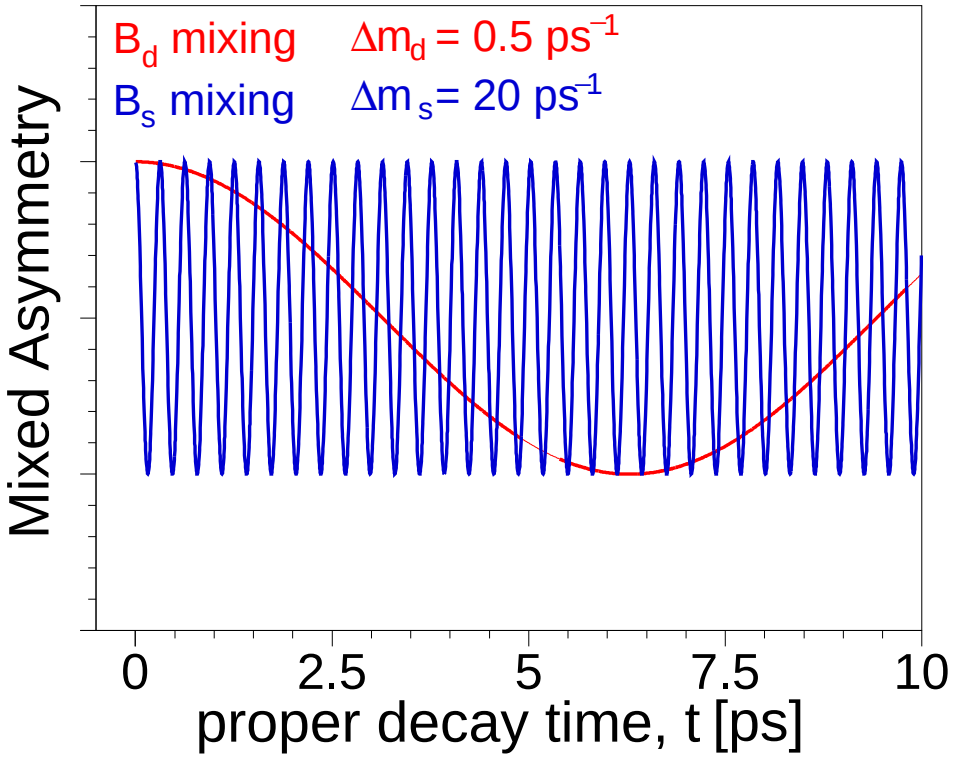
2) Proper time measurement

3) Flavour tagging (main challenge at hadron colliders)

Time dependent asymmetry:

$$\mathcal{A}(t) \equiv \frac{N(t)_{mixed} - N(t)_{unmixed}}{N(t)_{unmixed} + N(t)_{mixed}} = \mathcal{D}\cos(\Delta m_s t), \qquad \mathcal{D} = 1 - 2P_{mistag}$$

B_s Mixing is extremely fast!



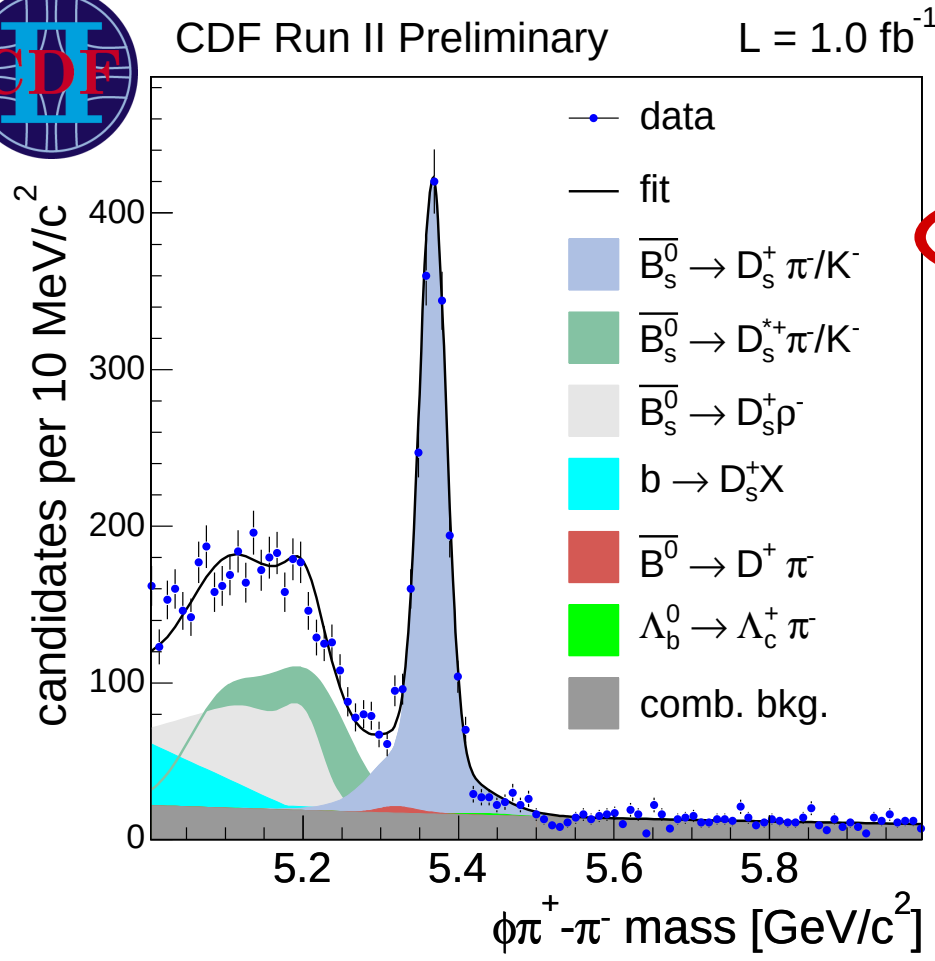
significance:

$$\sqrt{\frac{S\epsilon D^2}{2}}\sqrt{\frac{S}{S+B}}e^{-\frac{(\Delta m_s \sigma_{ct})^2}{2}}$$

Requirements

- High vertex resolution
- High momentum resolution
- Many signal events
- Good tagging performance

Hadronic B_s Channels

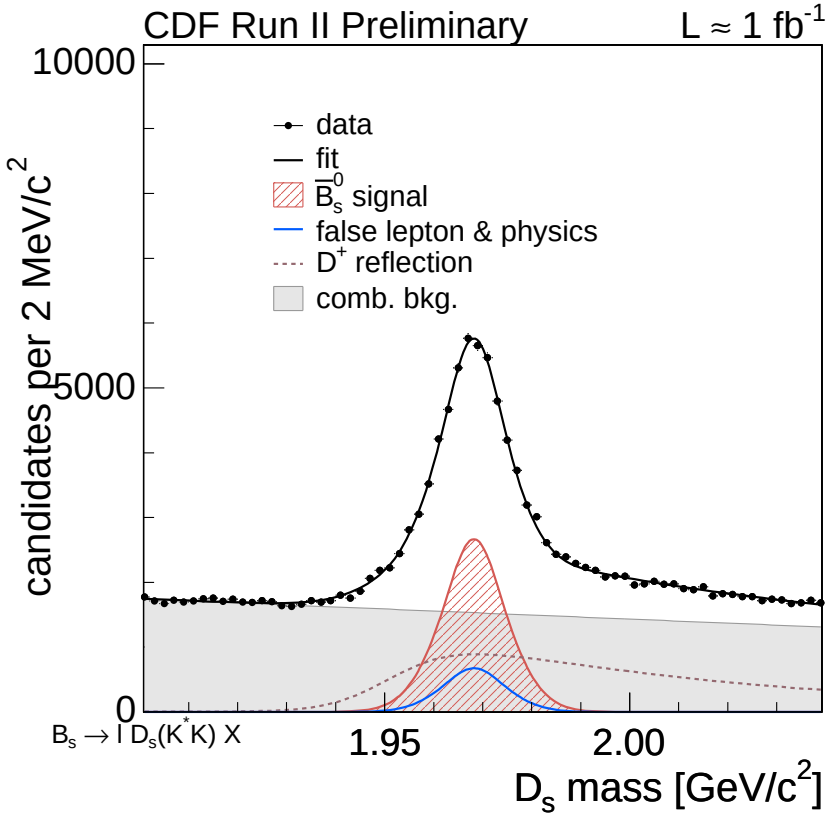


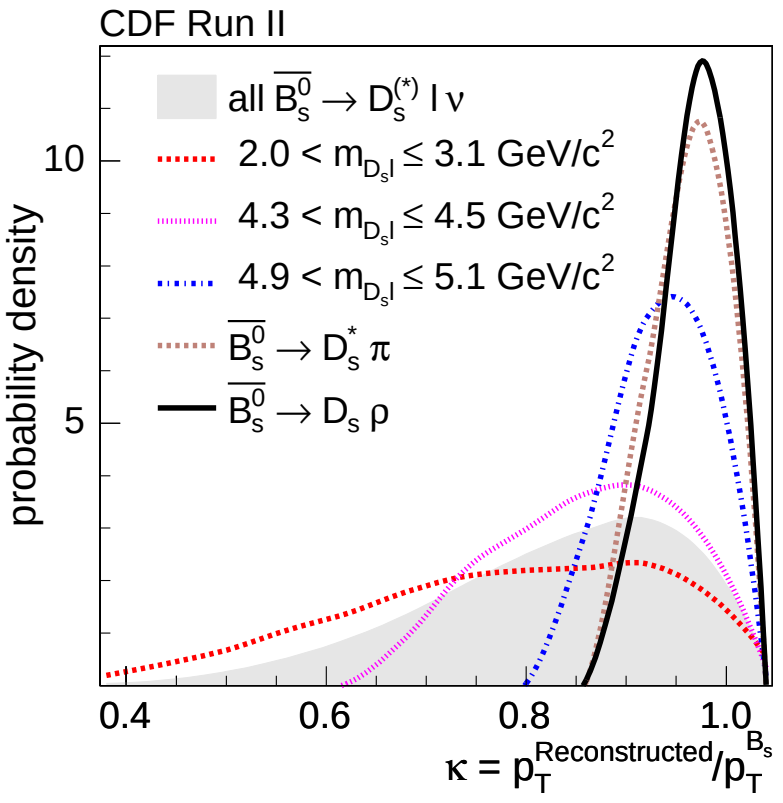
Golden Channel

decay	#
$B_s \to D_s(\phi\pi)\pi$	2000
$B_s \to D_s^*(\phi\pi)\pi, B_s \to D_s(\phi\pi)\rho$	3200
$B_s \to D_s(K^*K)\pi$	1400
$B_s \to D_s(3\pi)\pi$	700
$B_s \to D_s(\phi\pi)3\pi$	700
$B_s \to D_s(K^*K)3\pi$	600
$B_s \to D_s(3\pi)3\pi$	200

Hadronic modes selected by Two Track Trigger!

$B_s \to \ell D_s X$ Decays

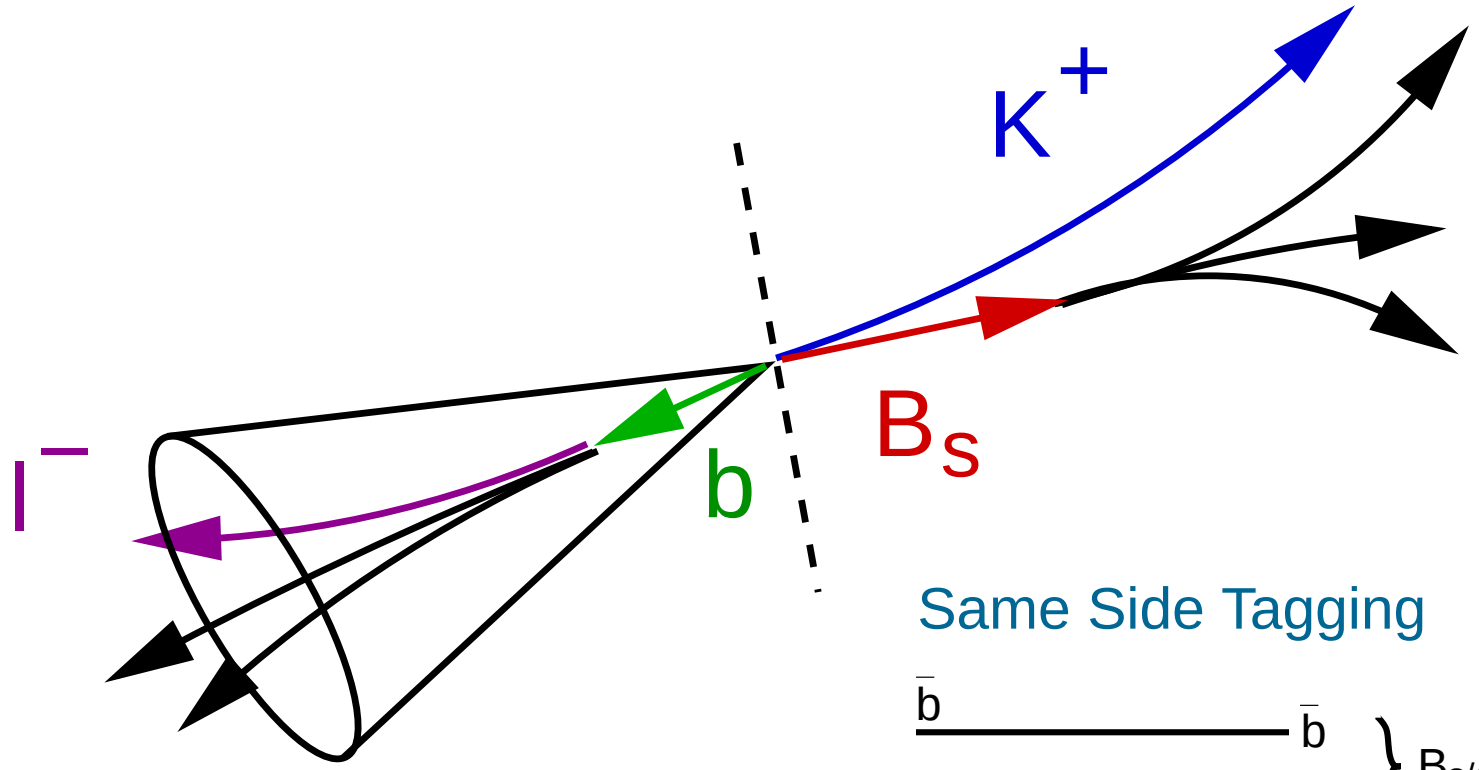




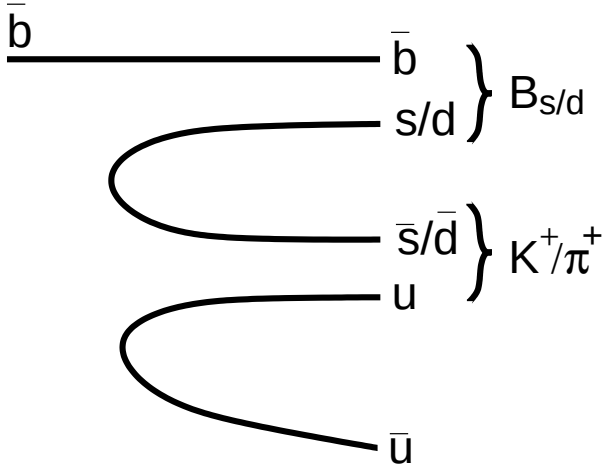
$\sim$ 61.500 semileptonic B_s decays

High statistic, low proper time resolution: $ct = \frac{L_{xy} m(B)}{p_T(B)} = \frac{L_{xy} m(B)}{p_T(\ell D)} * K$

Flavour Tagging



Same Side Tagging

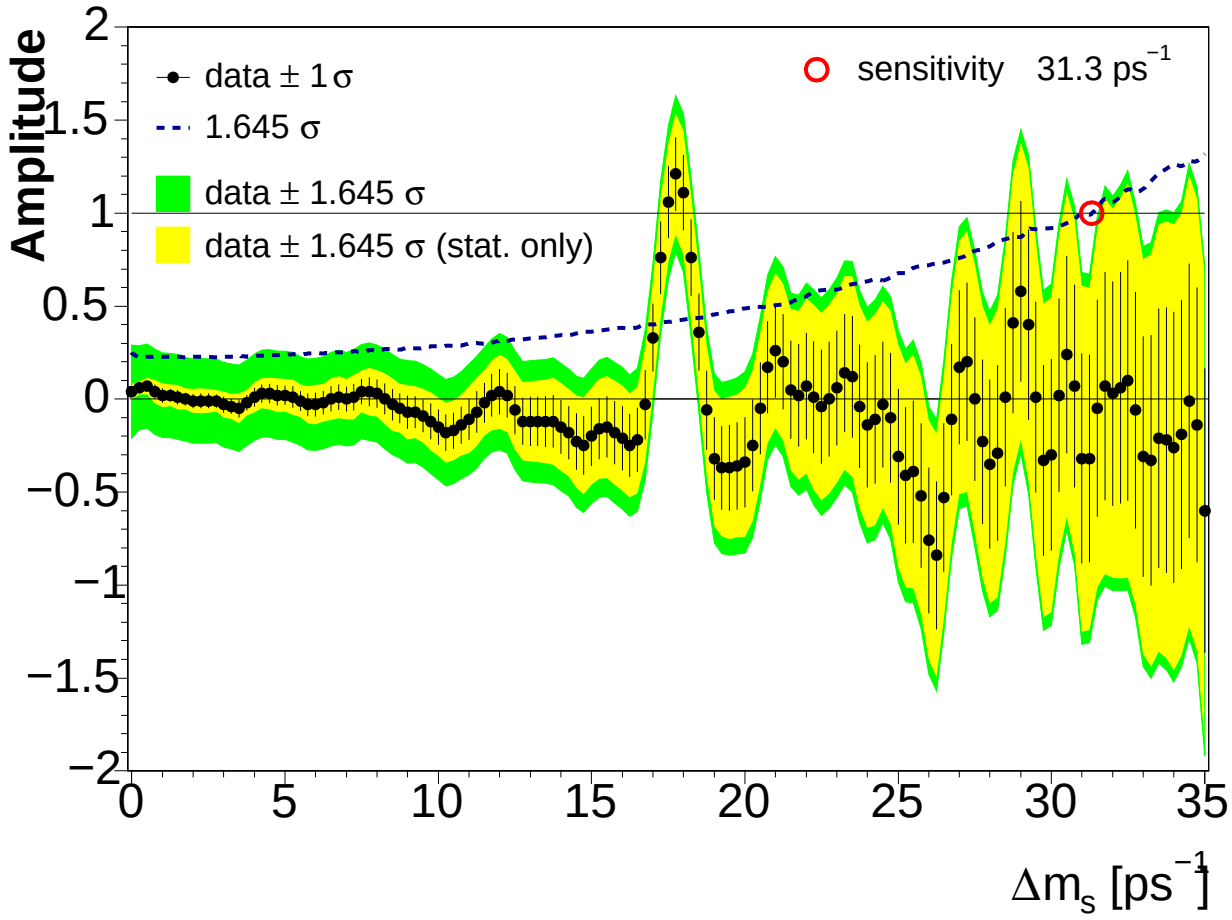


Opposite Side Tagging

ϵD^2 = 1.8 %

ϵD^2(had.) = 3.8 %, ϵD^2(semil.) = 4.8 %

Amplitude Scan



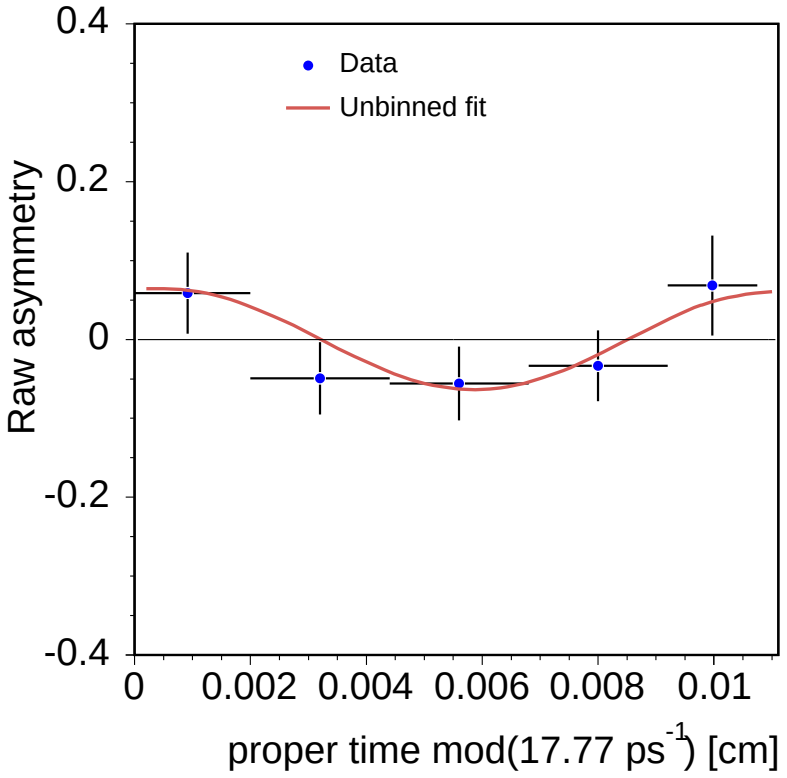
Probability of fluctuation $\leq 8 \times 10^{-8} \rightarrow > \mathbf{5\,\sigma}$

$\Delta m_s = 17.77 \pm 0.10(\text{stat.}) \pm 0.07(\text{syst.})\ \text{ps}^{-1}$

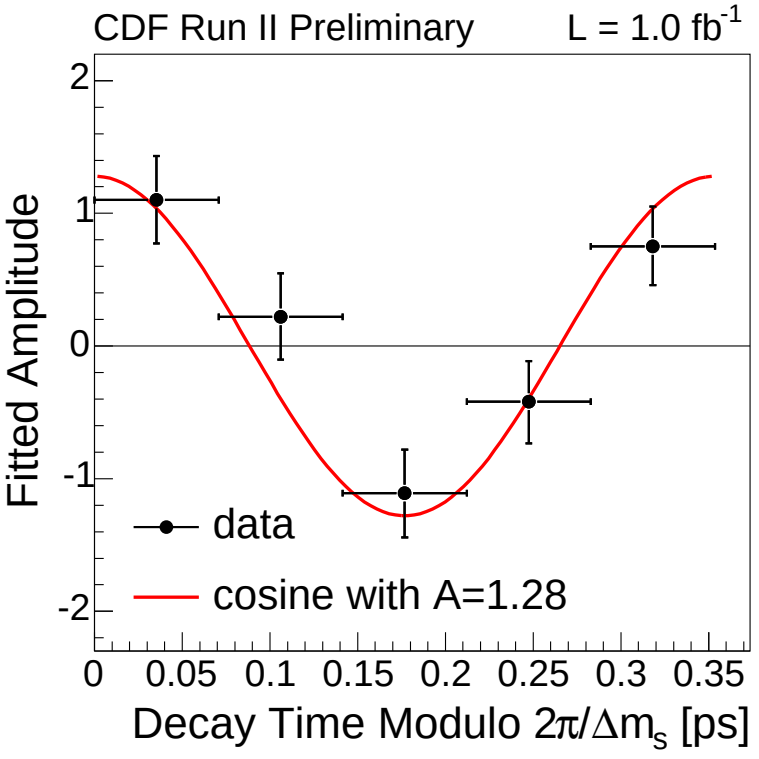
(PRL 97, 242003(2006))

Is This Visible?

All events with
tagging dilution > 10%



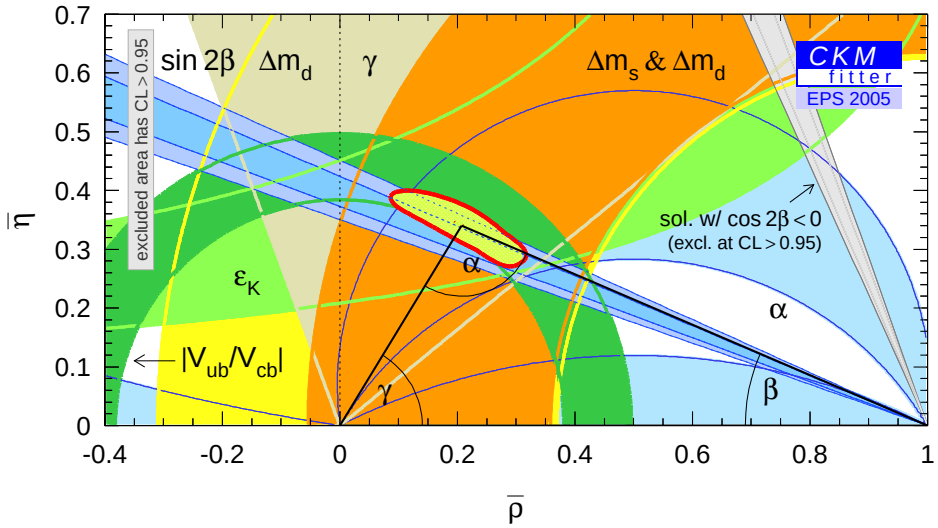
Weighted events
(tagging dilution, σ_{ct}, S/B ...)



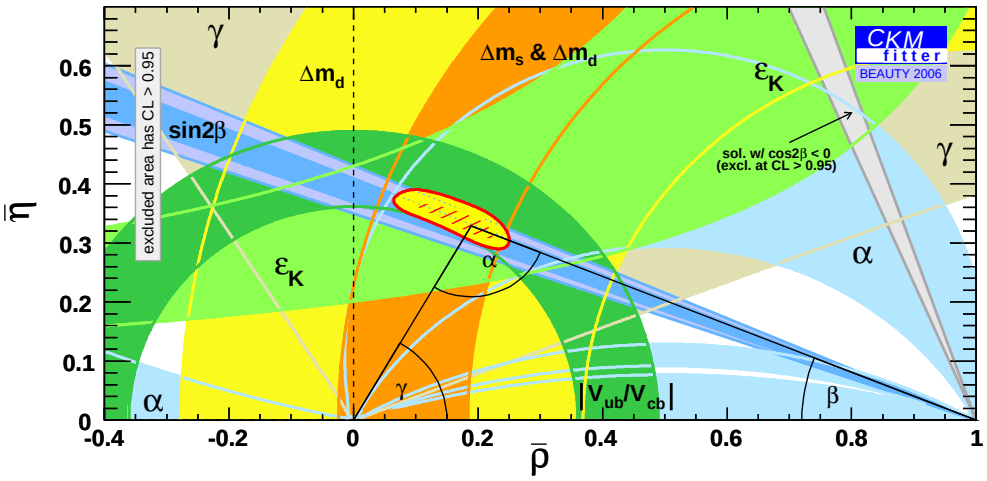
unbinned likelihood fit

Result on $|V_{td}|/|V_{ts}|$

summer '05



autumn '06

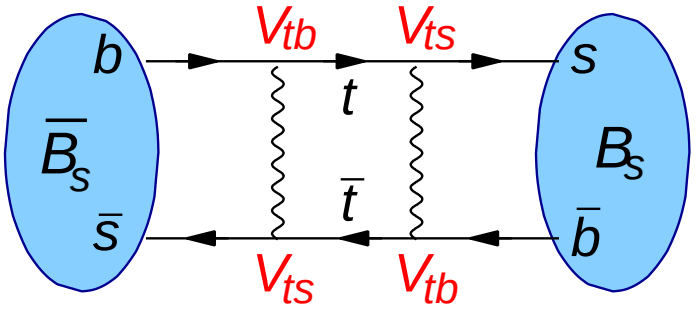


$$|V_{td}|/|V_{ts}| = 0.2061 \pm 0.0007\ (\text{exp.})\ {}^{+0.0081}_{-0.0060}\ (\text{theo.})$$

(hep-ex/0702049)

consistent with direct measurements - dominated by theoretical uncertainties

Mixing & CP Violation



flavor eigenstates B & $\bar{B} \neq$ mass eigenstates B_H & B_L

1) $\Delta m = m_H - m_L$ ✔

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

3) CP violation in mixing: ϕ

if $\phi = 0 \rightarrow$ mass eigenstates $\equiv$ CP eigenstates

$CP(B_H) = +1$ (CP even), $CP(B_L) = -1$ (CP odd)

SM prediction: $\Delta\Gamma$ = 0.10 $\pm$ 0.03 ps^{-1}, ϕ = -0.03 $\pm$ 0.005 (hep-ph/0406300)

$B_s \to J/\Psi\phi$

$P \to VV$ decay: polarization states $\equiv$ CP eigenstates

A_0: S + D wave $\to$ P even

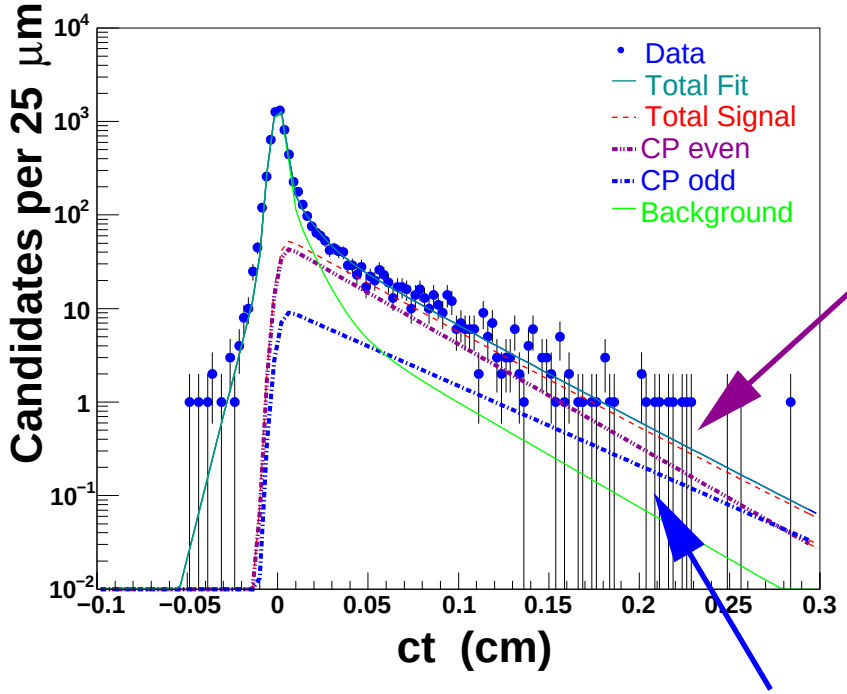
$A_\parallel$: S + D wave $\to$ P even

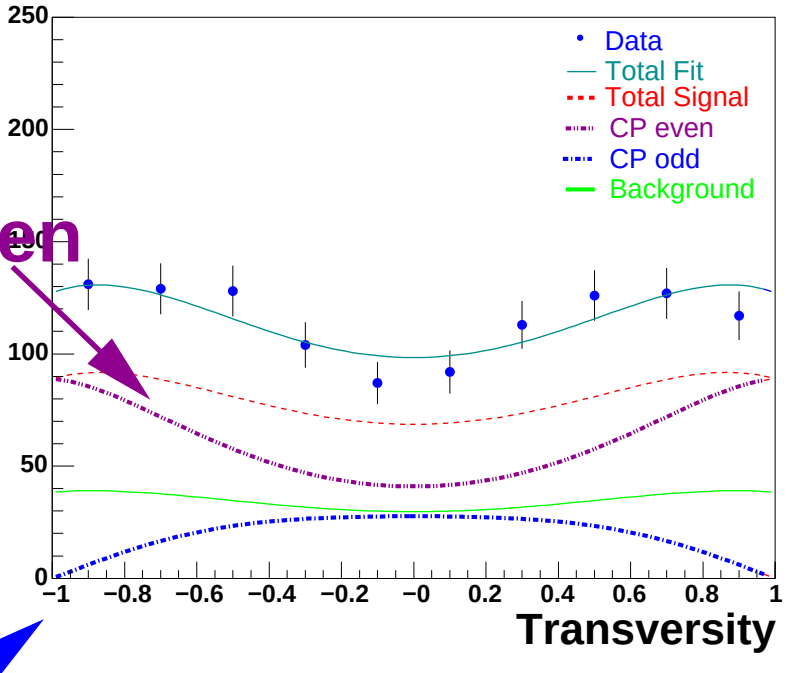
$A_\perp$: P wave $\to$ P odd

without CP violation:

$B_{s,L} \to CP$ even

$B_{s,H} \to CP$ odd





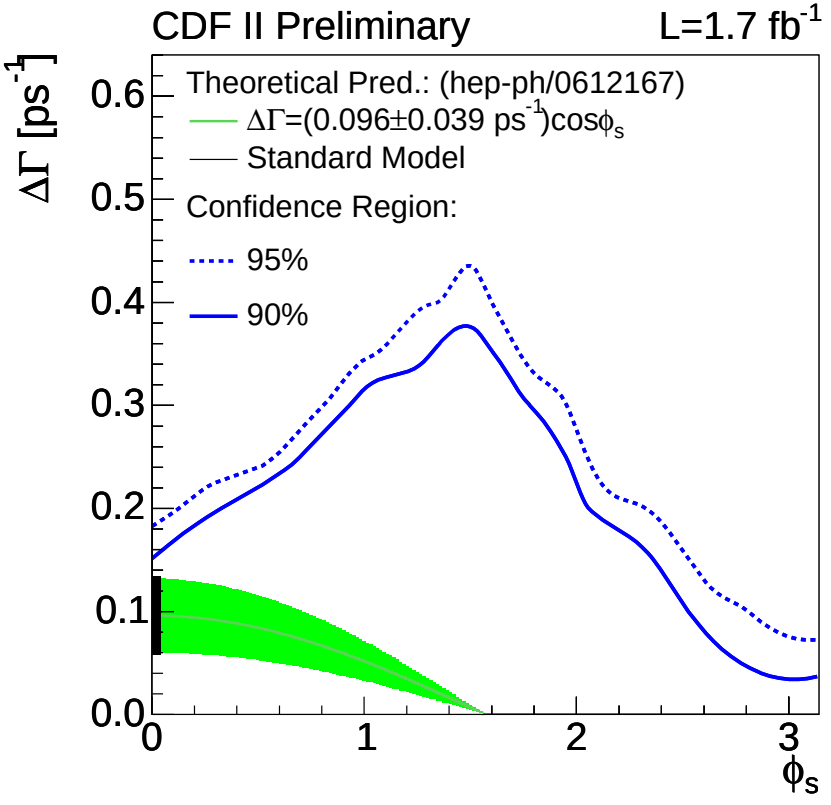
CP even
A_0, $A_\parallel$

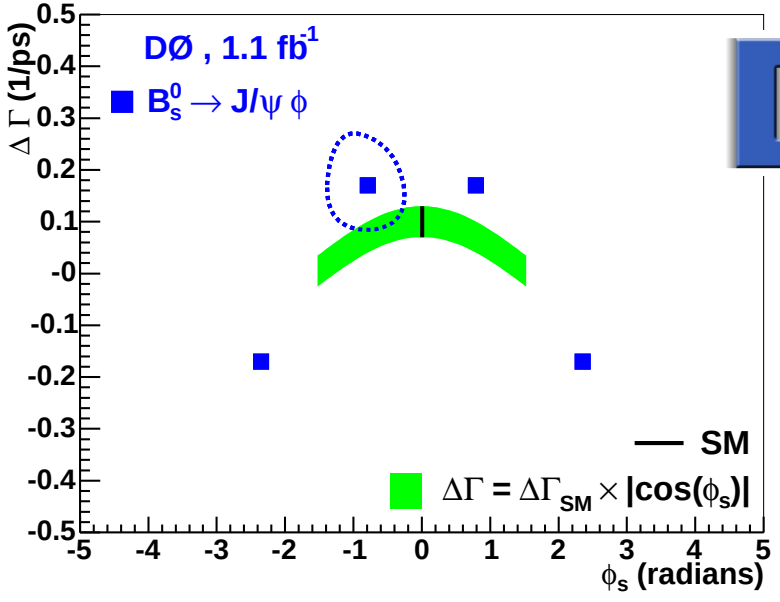
CP odd
$A_\perp$

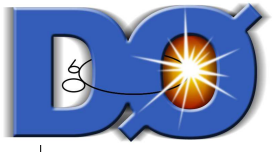
$\Delta\Gamma_s = 0.076\ ^{+0.059}_{-0.063}$ (stat.) $\pm$ 0.006 (syst.) ps^{-1}

ϕ_s = 0 (fixed)

- With tagging, expected $\times$ 1.5 improvement on uncertainties
- Still 4 $\times$ more data ahead







$\Delta\Gamma_s = 0.17 \pm 0.09$ (stat.) $\pm$ 0.02 (syst.) ps^{-1}

ϕ_s = -0.79 $\pm$ 0.56 (stat.) $^{+0.14}_{-0.01}$ (syst.)

B Physics @ the Tevatron

- Triggers crucial for any physics @ hadron colliders
- Very successful B program in challenging environment:
  - Δm_s = 17.77 $\pm$ 0.10 (stat.) $\pm$ 0.07 (syst) ps $^{-1}$
  - First measurement of the mixing parameters $\Delta\Gamma$ and ϕ_s
  - Observation of B hadrons: Ξ_b, Σ_b, B_c, λ_b, B_s^{**}, ..
  - ...
- Hadron colliders are precision measurement experiments
- Further interesting results expected with up to 6 fb^{-1}

Backup

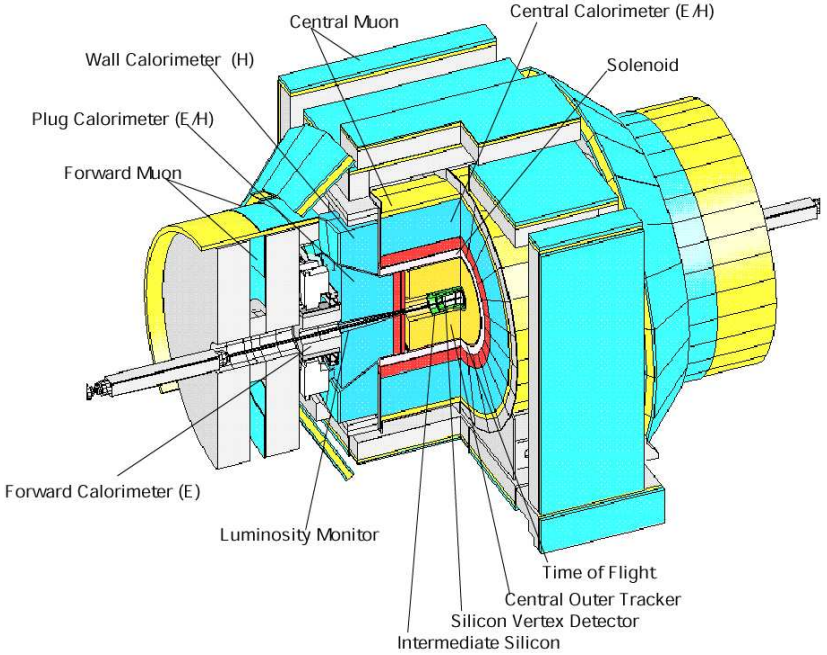
CDF versus D0

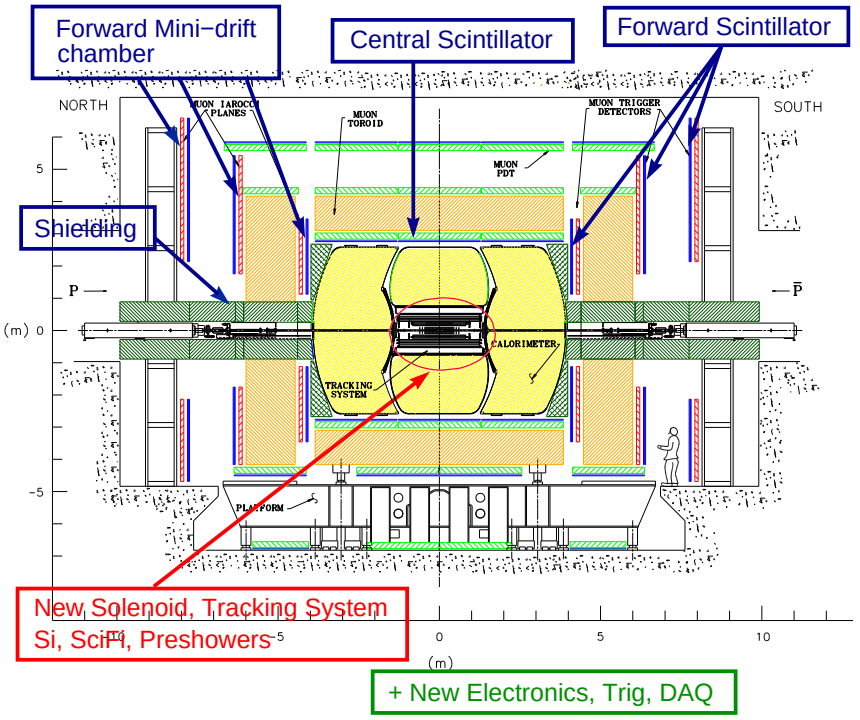
CDF

- Two displaced Track Trigger (TTT)
- Particle ID (dE/dx & TOF)
- Silicon layer close to interaction

strong in hadronic decays

good kaon tagging





D0

- Excellent Muon coverage
- High forward acceptance

strong in semi-muonic decays

excellent muon tagging

FCNC: $B_{s(d)} \longrightarrow \mu^+\mu^-$

- SM: no tree level contribution, loops strongly suppressed

  BF($B_s \longrightarrow \mu^+\mu^-$) $= 3.5 \times 10^{-9}$

  BF($B_d \longrightarrow \mu^+\mu^-$) $= 1.0 \times 10^{-10}$

  G. Buchalla, A. Buras, Nucl. Phys. B398,285

- SM extensions predict up to $\times$ 1000 higher rates

  Each signal would be hint to new physics!

CDF results (1.9 fb^{-1}):

BR($B_s \longrightarrow \mu^+\mu^-$) $\leq 5.8 \times 10^{-8}$ @ 95% CL

BR($B_d \longrightarrow \mu^+\mu^-$) $\leq 1.8 \times 10^{-8}$ @ 95% CL

D0 results (2.0 fb^{-1}):

BR($B_s \longrightarrow \mu^+\mu^-$) $\leq 9.3 \times 10^{-8}$ @ 95% CL