B physics and Bs mixing at the Tevatron

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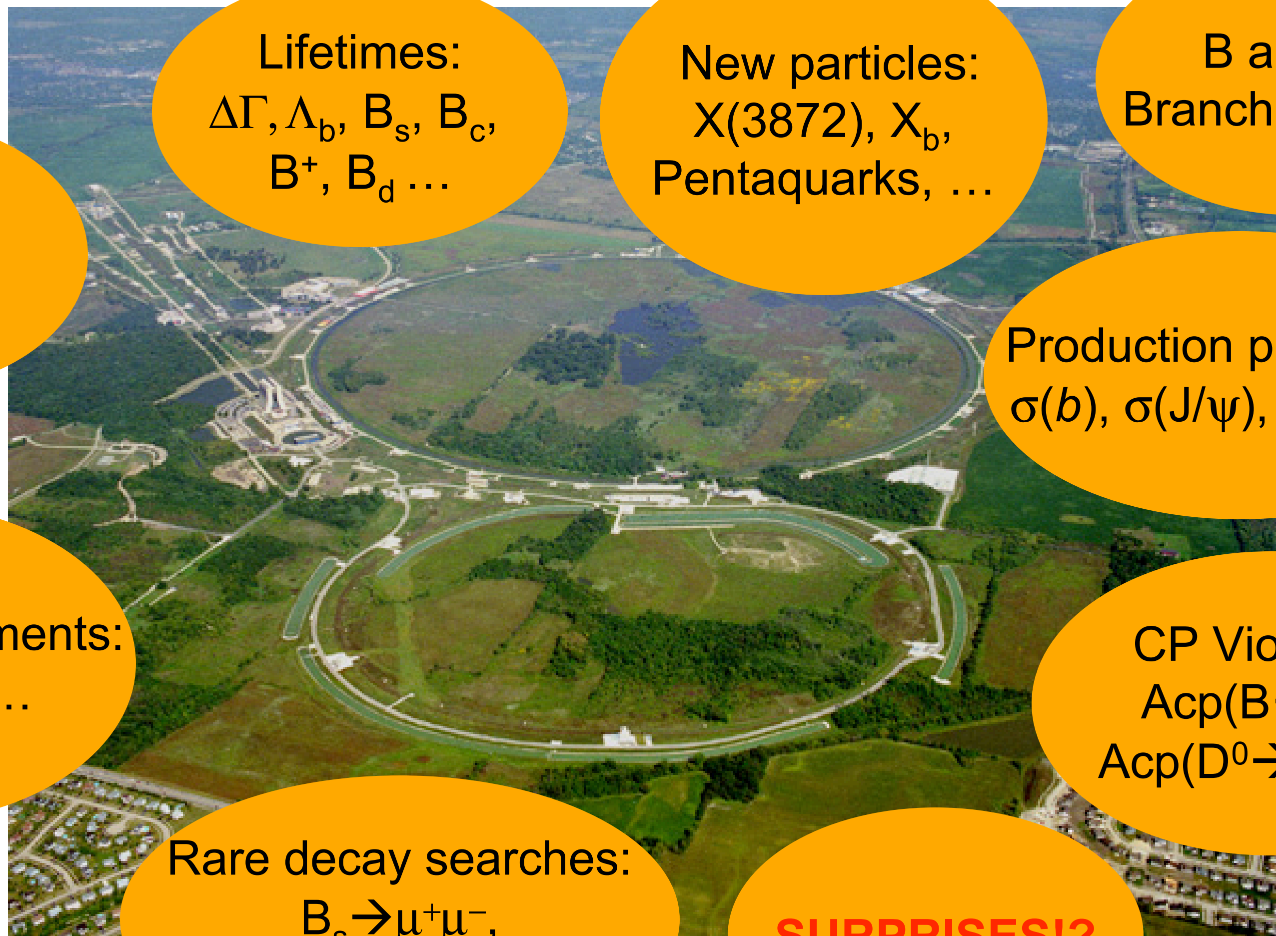
Rich Harvest of Heavy Flavor Physics at the Tevatron



Lifetimes:
$\Delta\Gamma$, Λ_b, B_s, B_c,
B^+, B_d …

New particles:
X(3872), X_b,
Pentaquarks, …

B and D
Branching ratios

Mixing:
B_s, B_d, D^0

Production properties:
$\sigma(b)$, $\sigma(J/\psi)$, $\sigma(D^0)$, …

Mass measurements:
B_c, Λ_b, B_s, …

CP Violation:
$Acp(B \rightarrow hh)$,
$Acp(D^0 \rightarrow K\pi)$, …

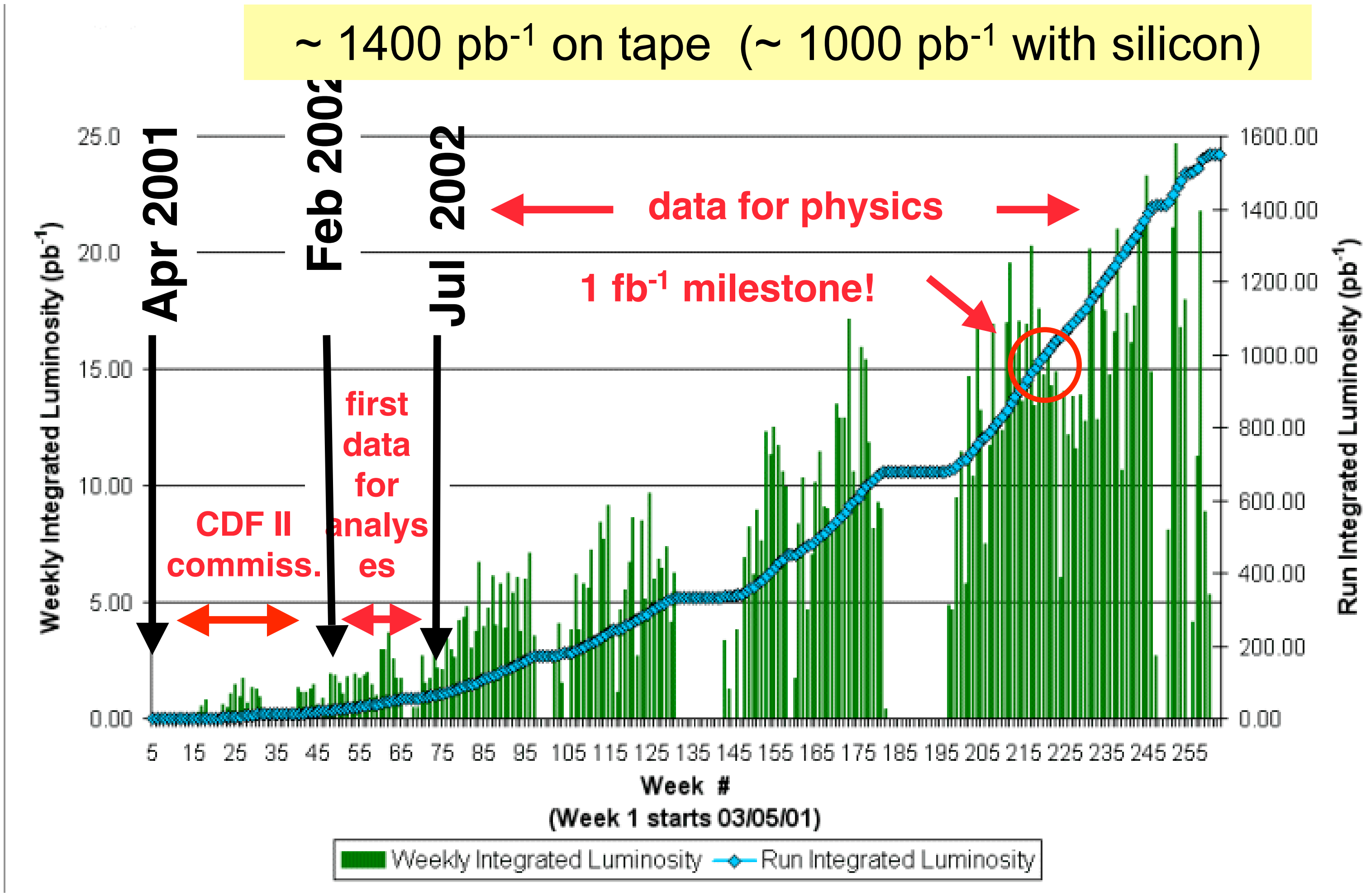
Rare decay searches:
$B_s \rightarrow \mu^+\mu^-$,
$D^0 \rightarrow \mu^+\mu^-$, …

SURPRISES!?

Outline

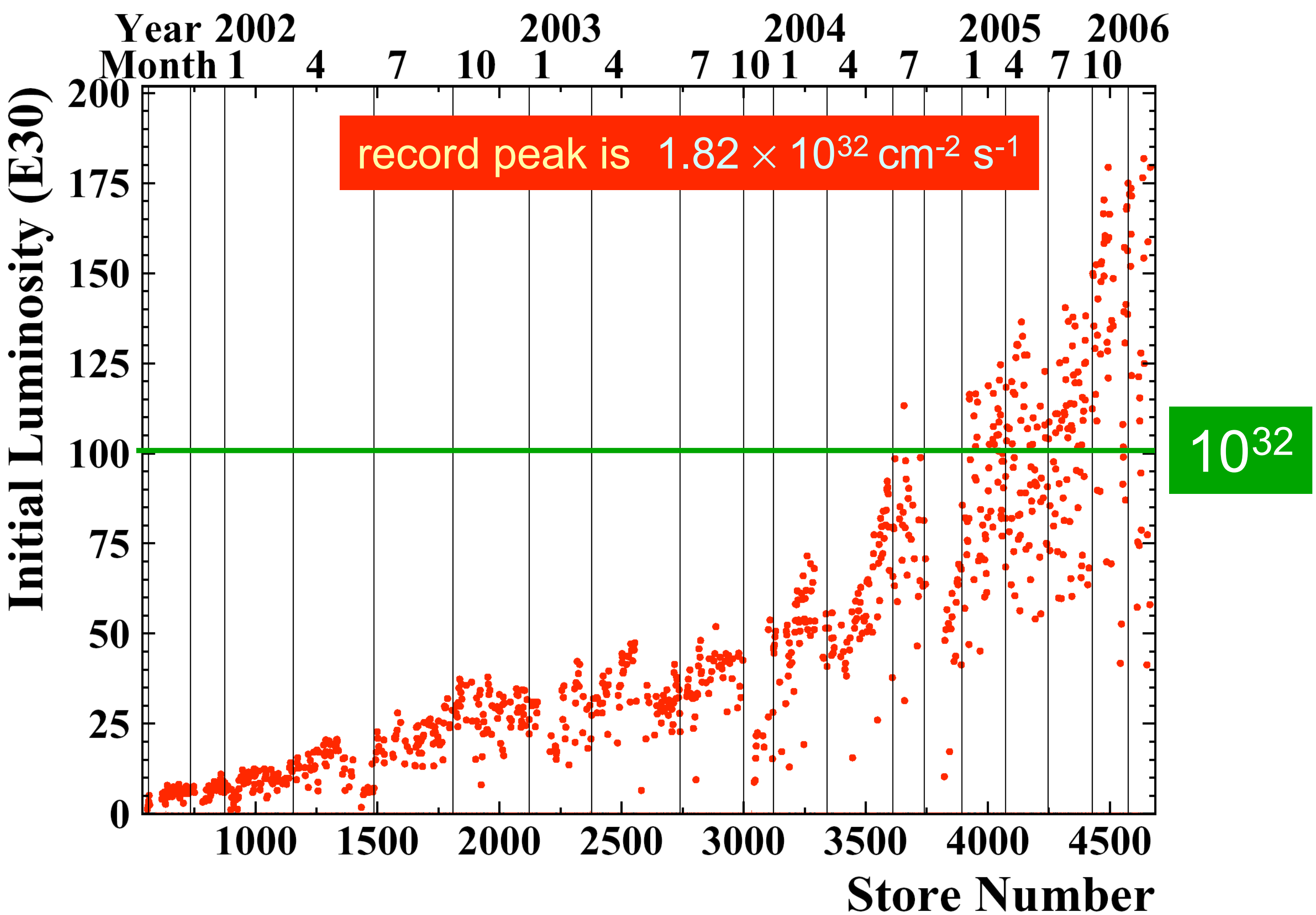
- Tevatron performance and Detectors
- Rare hadronic decays
- Rare leptonic decays
- Bs mixing
- $\Delta\Gamma_s$

Integrated luminosity

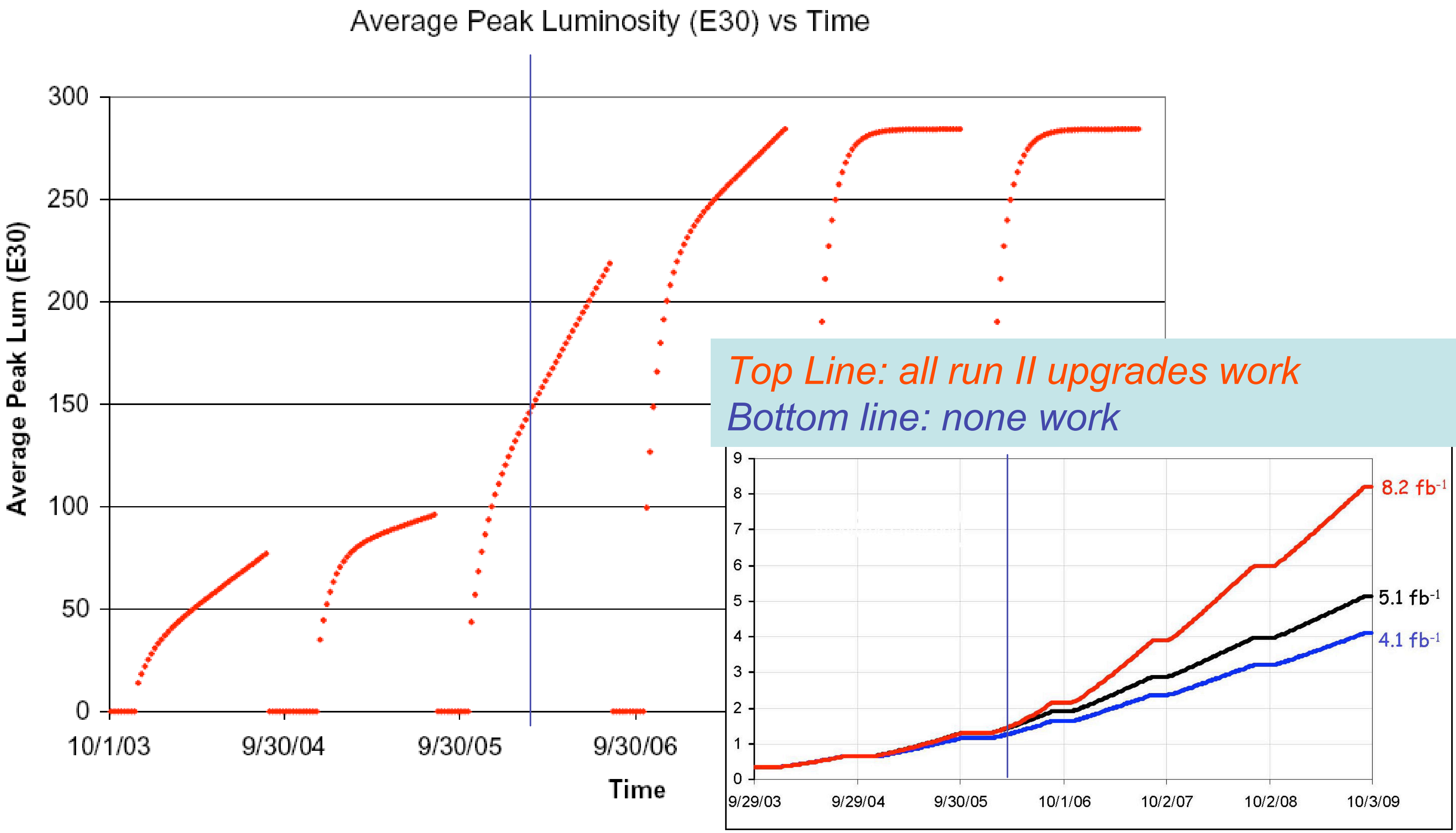


Stable data taking efficiency: > 85%. Results here use 360 - 780 pb^{-1}

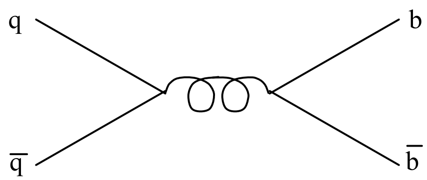
Instantaneous Luminosity



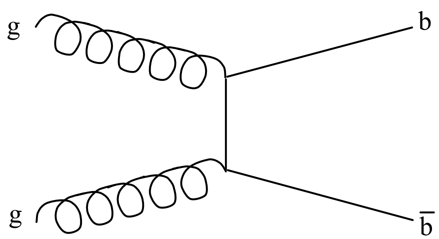
Projected Peak Luminosity



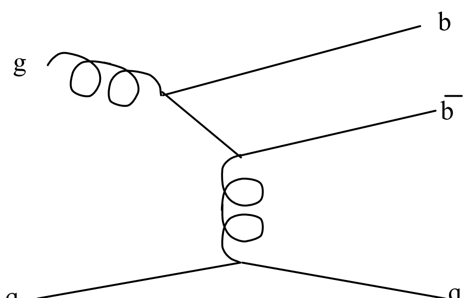
Heavy Flavor Physics In Hadron Environment



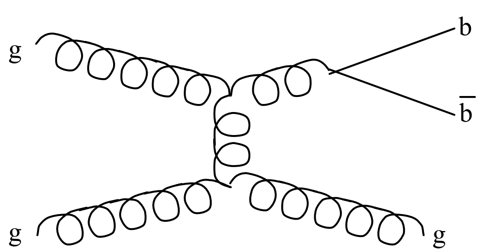
Flavor Creation (annihilation)



Flavor Creation (gluon fusion)



Flavor Excitation



Gluon Splitting

b's produced via strong interaction

decay via weak interaction

Tevatron is great for heavy flavor:

- Huge *b* production cross-section, x1000 times larger than e^+e^- B factories
- All B species are (incoherently) produced (B^0, B^+, Λ_b, B_s, etc…)

However,

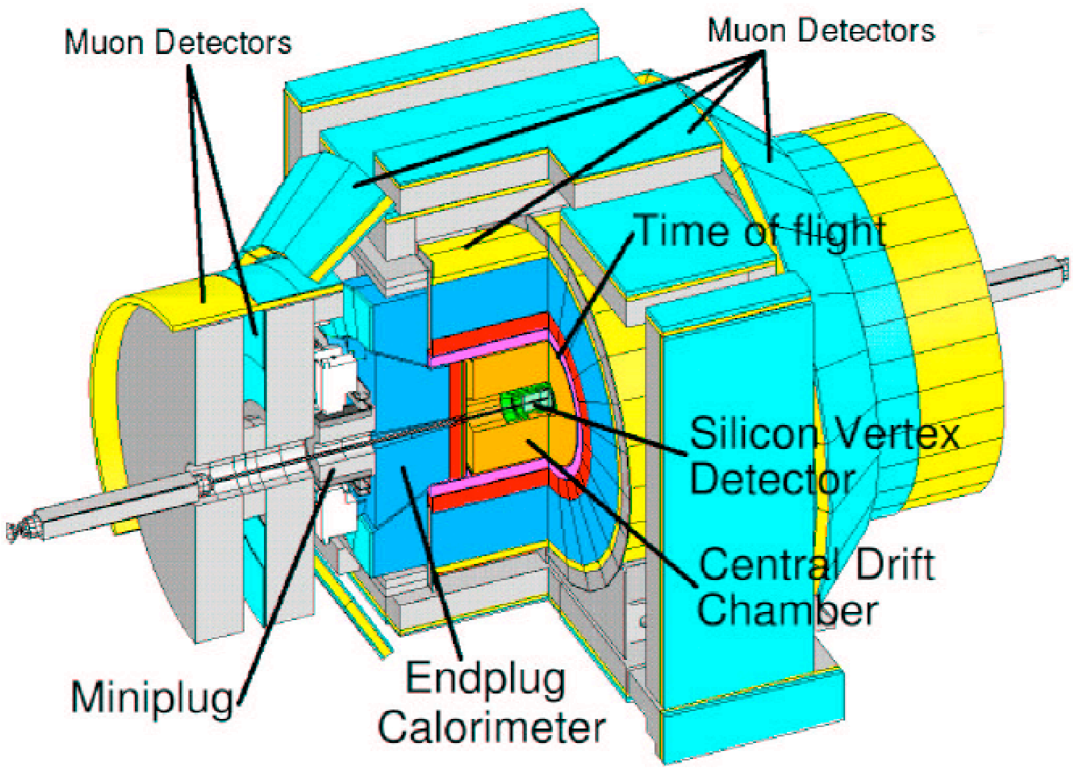
- x1000 QCD background
- Trigger and reconstruction is a challenge: crossing rate 2.5 MHz → tape writing limit ~100Hz
- Efficiency small, $\sigma\times\varepsilon$ "pretty good"

  $\Rightarrow$ "Live and Die by the trigger"

The CDFII Detector

- multi-purpose detector
- excellent momentum resolution $\sigma(p)/p<0.1\%$

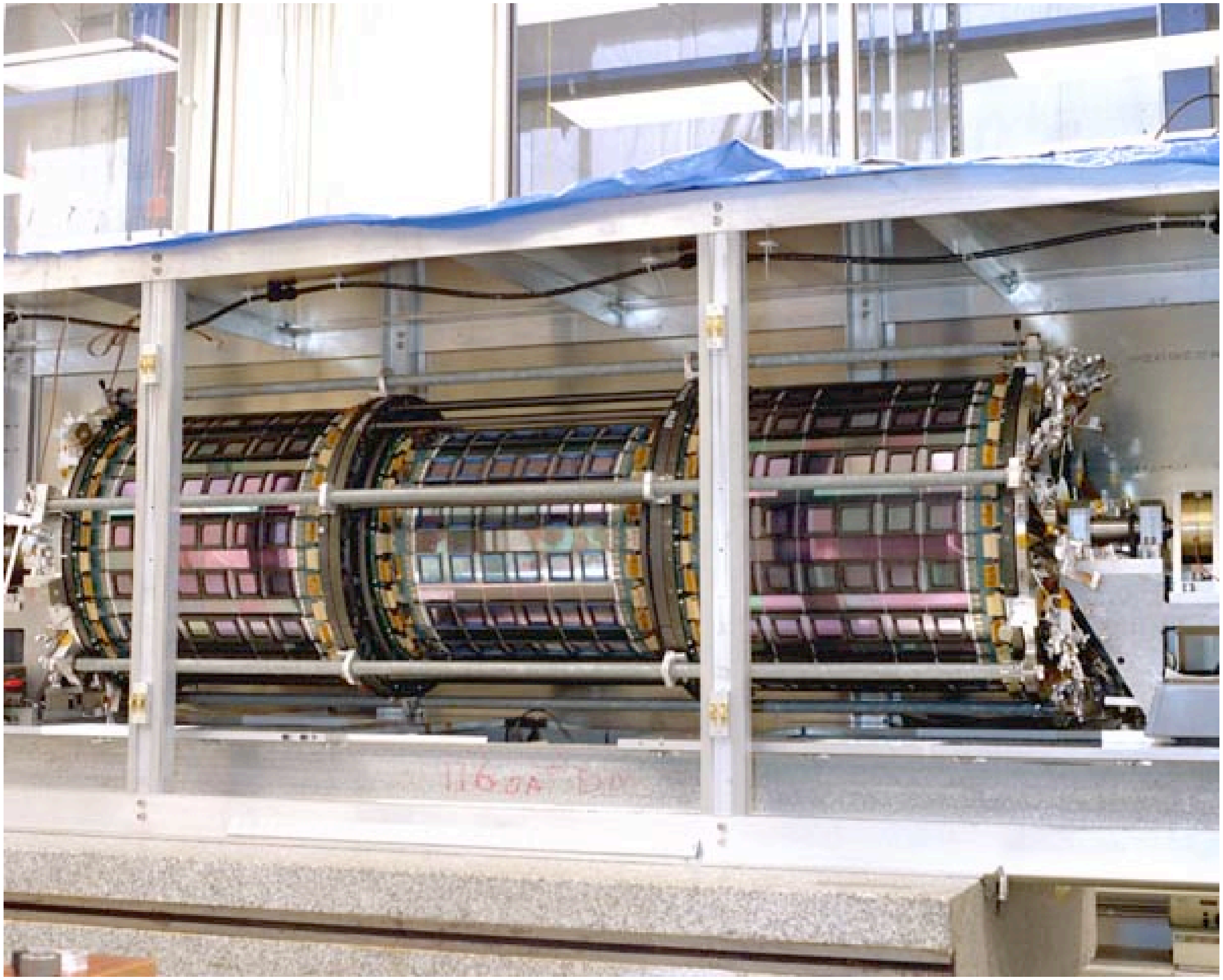
- Yield:
  - SVT based triggers
- Tagging power:
  - TOF, dE/dX in COT
- Proper time resolution:
  - SVXII, L00



CDF II silicon tracker

Visible ISL
Inside:
- **SVX-II**
- **L00**

Major INFN contributions to all of them



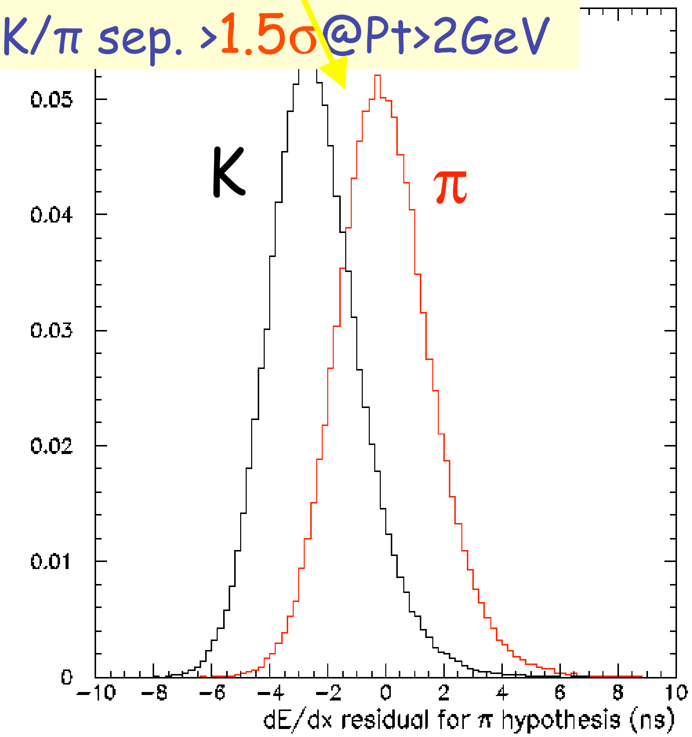
PID at CDF

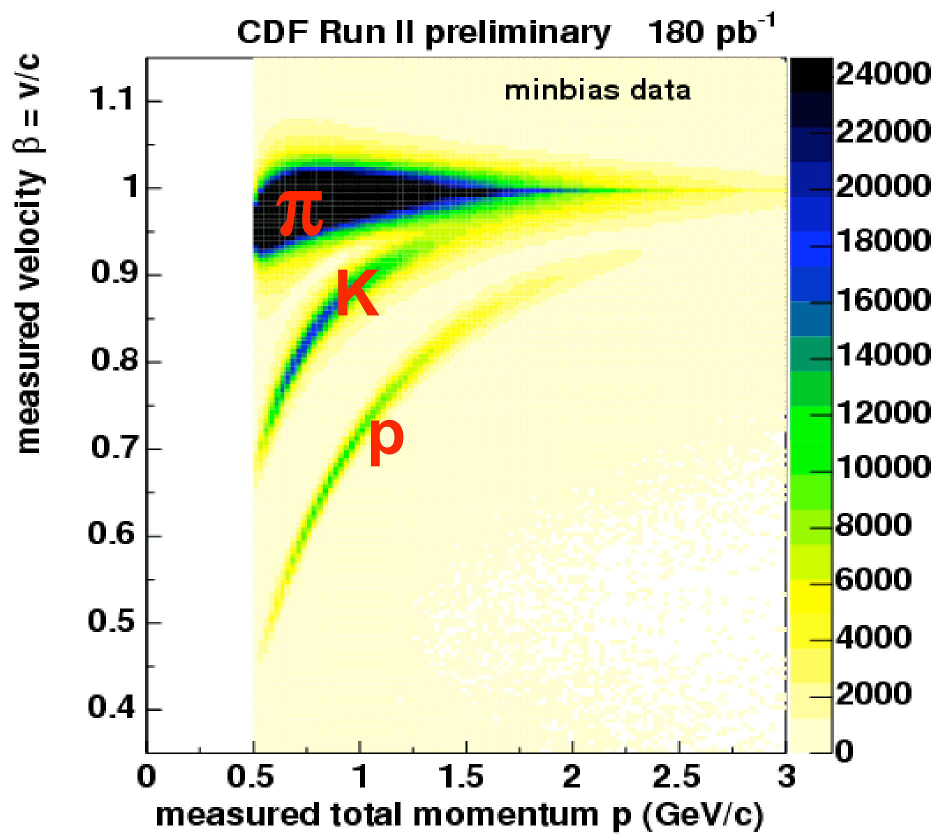
Significant INFN contribution

- Time of Flight
- dE/dx in COT

dE/dx in COT

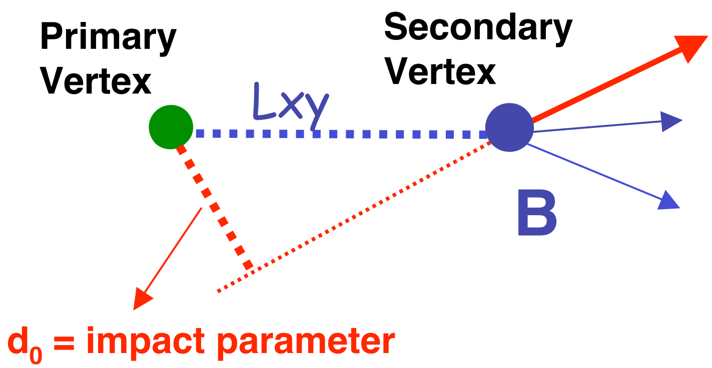
K/π sep. >1.5σ@Pt>2GeV



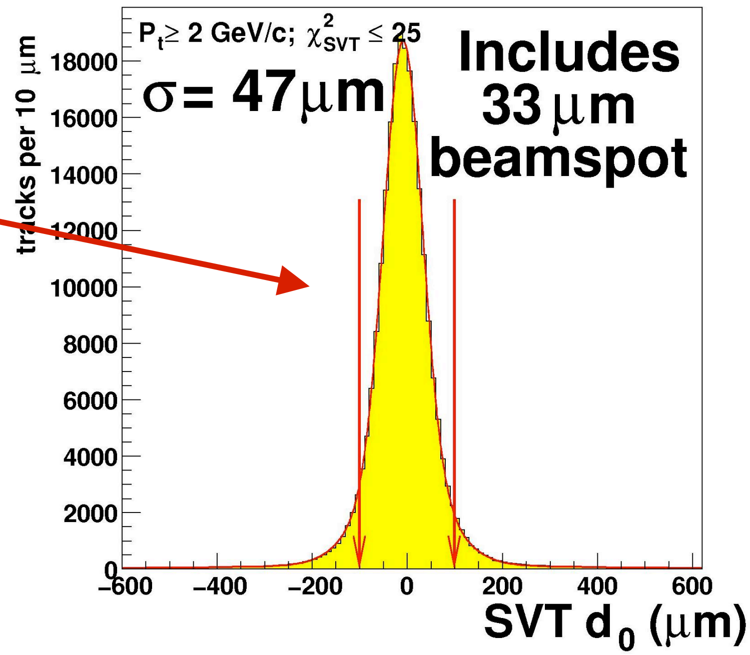


TOF: >1σ K/π separation up to p=2 GeV

CDF Trigger On Displaced Tracks



Major INFN contribution



Find tracks in SVX in 20 μs with offline accuracy

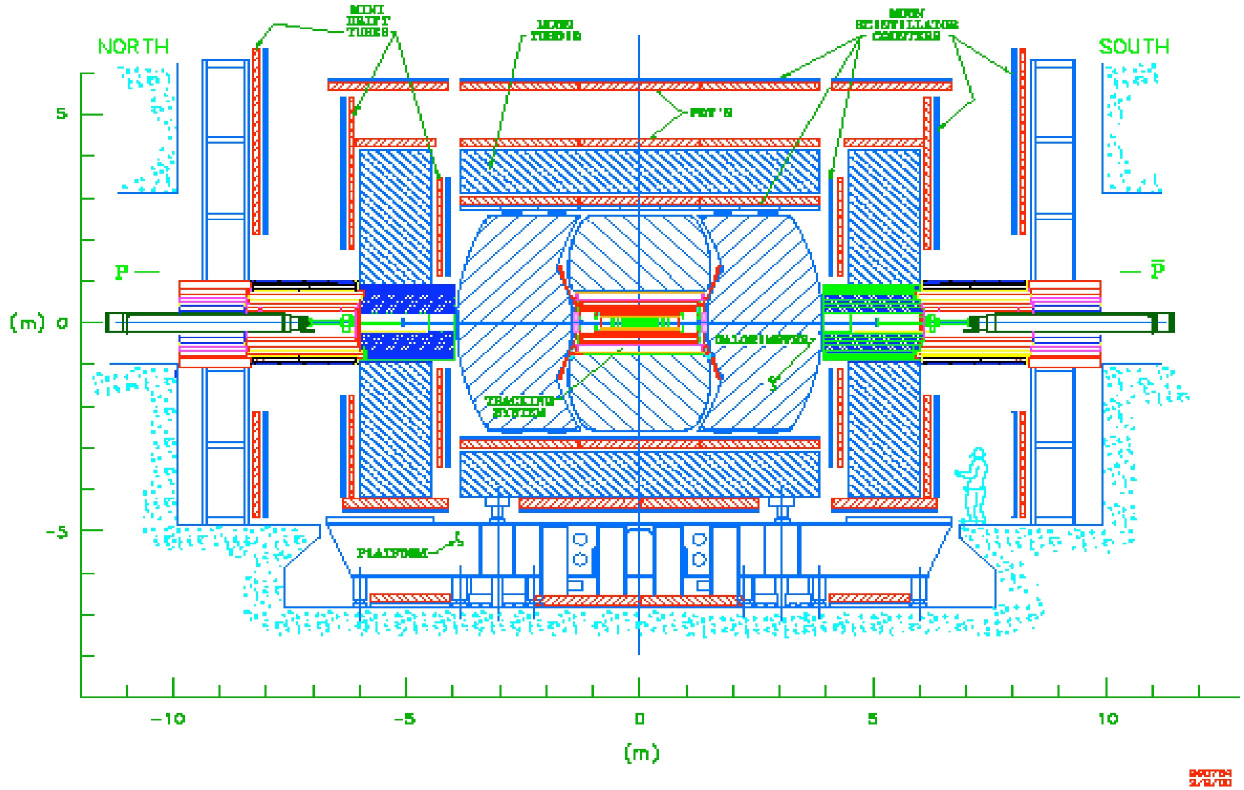
“Unusual” trigger requirement:

Two displaced tracks:

(p_T > 2 GeV/c, 120 μm<$|d_0|$<1mm)

Requires precision tracking in SVX

D0 Detector



B Physics Program based on excellent performance of

1) muon system, ***|η|<2.0, pT > 3,4,5 GeV***

2) silicon microstrip tracker

3) Good single and dimuon triggers

4) New innermost silicon layer being installed

Charmless hadronic

$B_d, B_s \rightarrow h^+h^-$

Signal yield: ~2300
S/B ≈ 6.5 (peak val

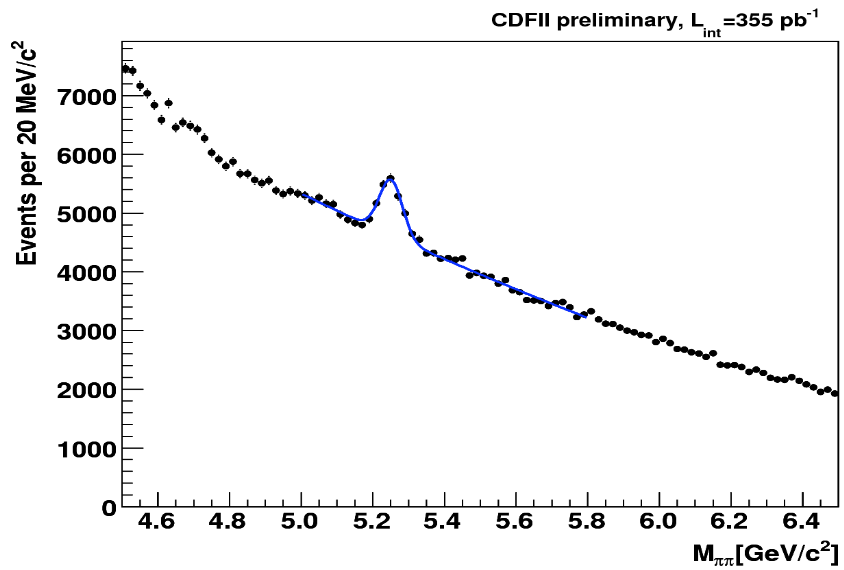
Crucial requiremen

✓Trigger on 2 displ

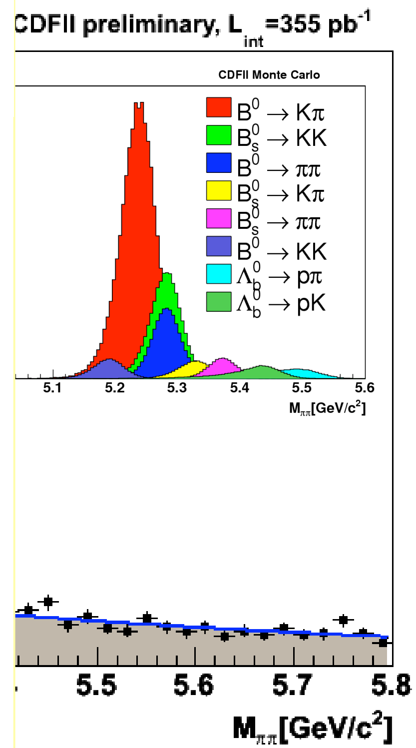
✓ isolation of the *B*
reject light quark

✓ 3D-tracks to rejec
combinatorics fro

BR~10^{-5} visible with just trigger confirmation !



a bump of ~3850 events with S/B ≈ 0.2 (at peak) in $\pi\pi$-invariant mass

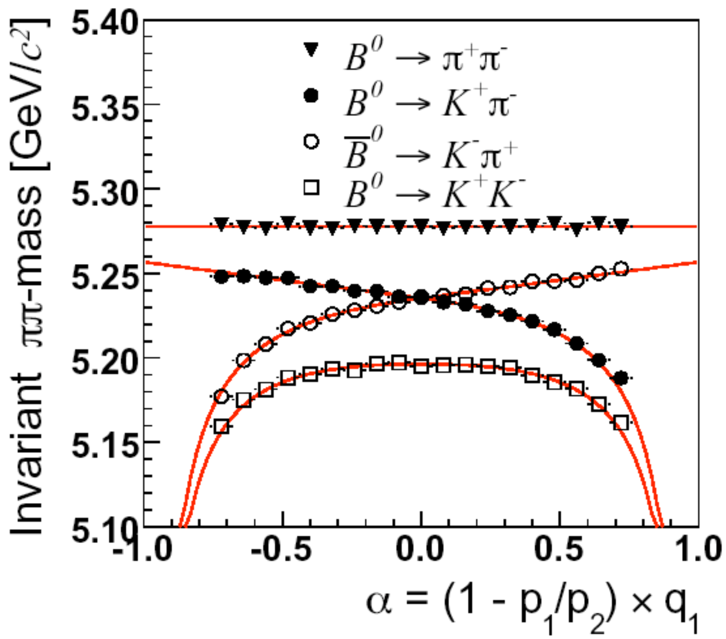


Despite excellent m ... p into an
unresolved mass p

Fit signal compositi ... mation from
kinematics (masses and momenta) *and* particle ID (dE/dx).

Separating contributions

Kinematics

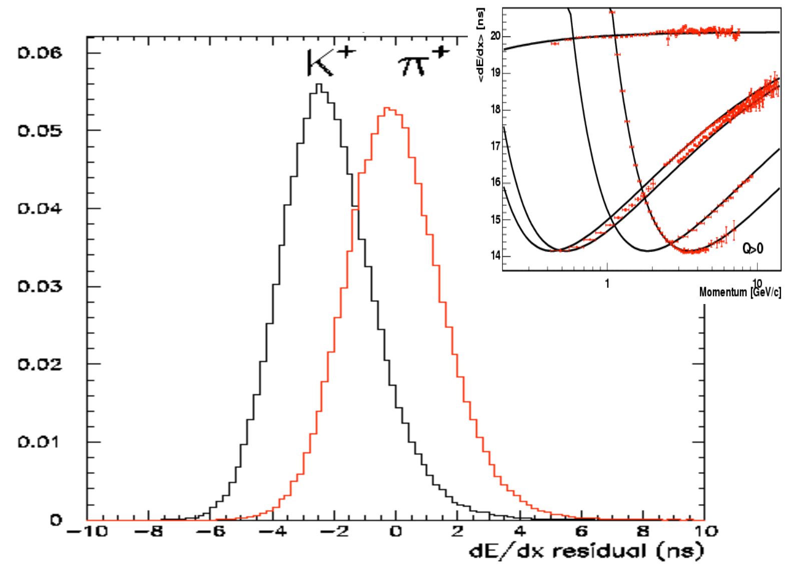


Separation power provided by Mass vs momentum imbalance α

Also distinguish $K^+\pi^-$ from $K^-\pi^+$

$\Rightarrow$ Direct A_{CP}

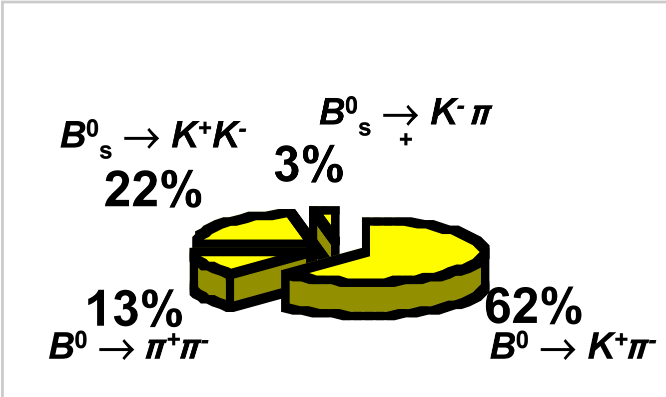
dE/dx



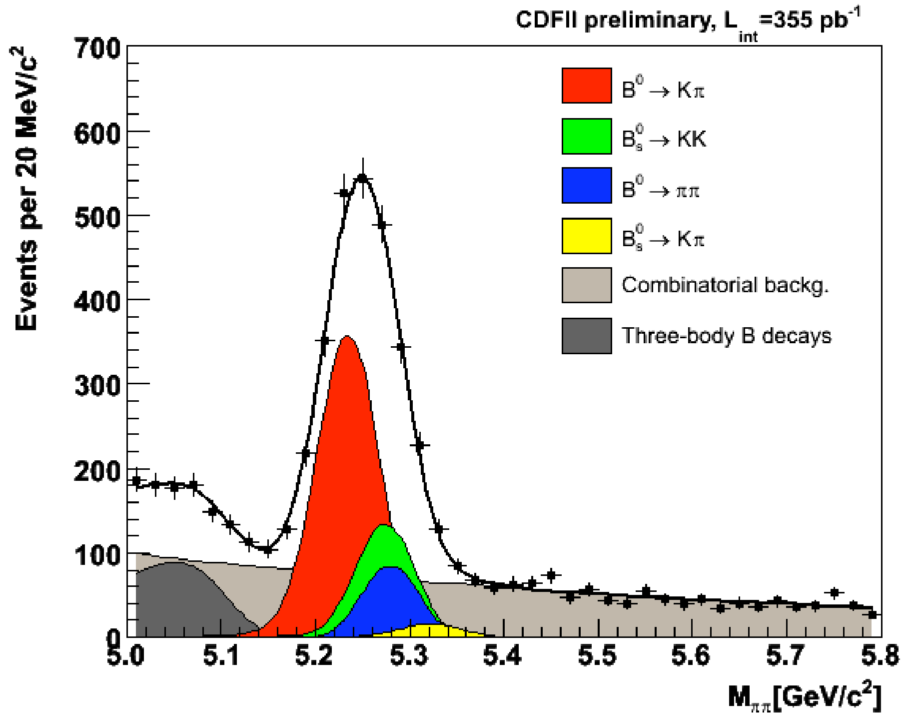
1.4σ K/π separation at p > 2 GeV

(≡ 60% of "perfect" separation)

Raw Yields



mode	fraction [%]	yield
$B^0 \to \pi^+\pi^- + \overline{B}^0 \to \pi^+\pi^-$	13.2 ± 1.4	313 ± 34
$B^0_s \to K^-\pi^+ + \overline{B}^0_s \to K^+\pi^-$	2.7 ± 1.3	64 ± 30
$B^0_s \to K^+K^- + \overline{B}^0_s \to K^+K^-$	22.0 ± 1.6	523 ± 41
$B^0 \to K^+\pi^- + \overline{B}^0 \to K^-\pi^+$	62.1 ± 1.7	1475 ± 60
$B^0 \to K^+\pi^-$	–	787 ± 42
$\overline{B}^0 \to K^-\pi^+$	–	689 ± 41



- Small corrections needed to convert it into BR's - Old results ($180pb^{-1}$) were world's best for all Bs modes.
  - Now expect $B_s \to KK$ to <10%.
  - $B_s \to K\pi$ limit was at the bottom of theoretical expectations, now 2σ
  - Also measure annihilation modes $B_d \to KK$ and $B_s \to \pi\,\pi$

New Result: $A_{CP}(B^0 \rightarrow K^+\pi^-)$ (360 pb^{-1})

$$A_{\mathrm{CP}}^{\mathrm{CDF}}(B^0 \to K^+\pi^-) = -0.058 \pm 0.039\ (stat.) \pm 0.007\ (syst.)$$

Result is ~1.5σ different from 0, and compatible with *B*-factories results:

$$A_{\mathrm{CP}}^{\mathrm{Belle}}(B^0 \to K^+\pi^-) = -0.113 \pm 0.022\ (stat.) \pm 0.008\ (syst.)$$

$$A_{\mathrm{CP}}^{\mathrm{Babar}}(B^0 \to K^+\pi^-) = -0.133 \pm 0.030\ (stat.) \pm 0.009\ (syst.)$$

Systematic uncertainties from CDF and *B*-factories are comparable.
Ongoing analysis on 1fb^{-1} will have ~2.5% statistical uncertainty

Expect to observe $B^0_s \rightarrow K^-\pi^+$ and measure BR and $A_{CP.}$ Important property of this mode in the SM (very weak assumptions!):

$$\frac{A_{CP}(B_s \to K^-\pi^+)}{A_{CP}(B_d \to K^+\pi^-)} = \frac{BR(B_d \to K^+\pi^-)}{BR(B_s \to K^-\pi^+)}$$

A crucial test of SM-origin of direct CP violation [Lipkin, Phys.Lett.B621:126, 2005].

BR analysis under SU(3) *including* annihilation and allowing factorizable SU(3) breaking

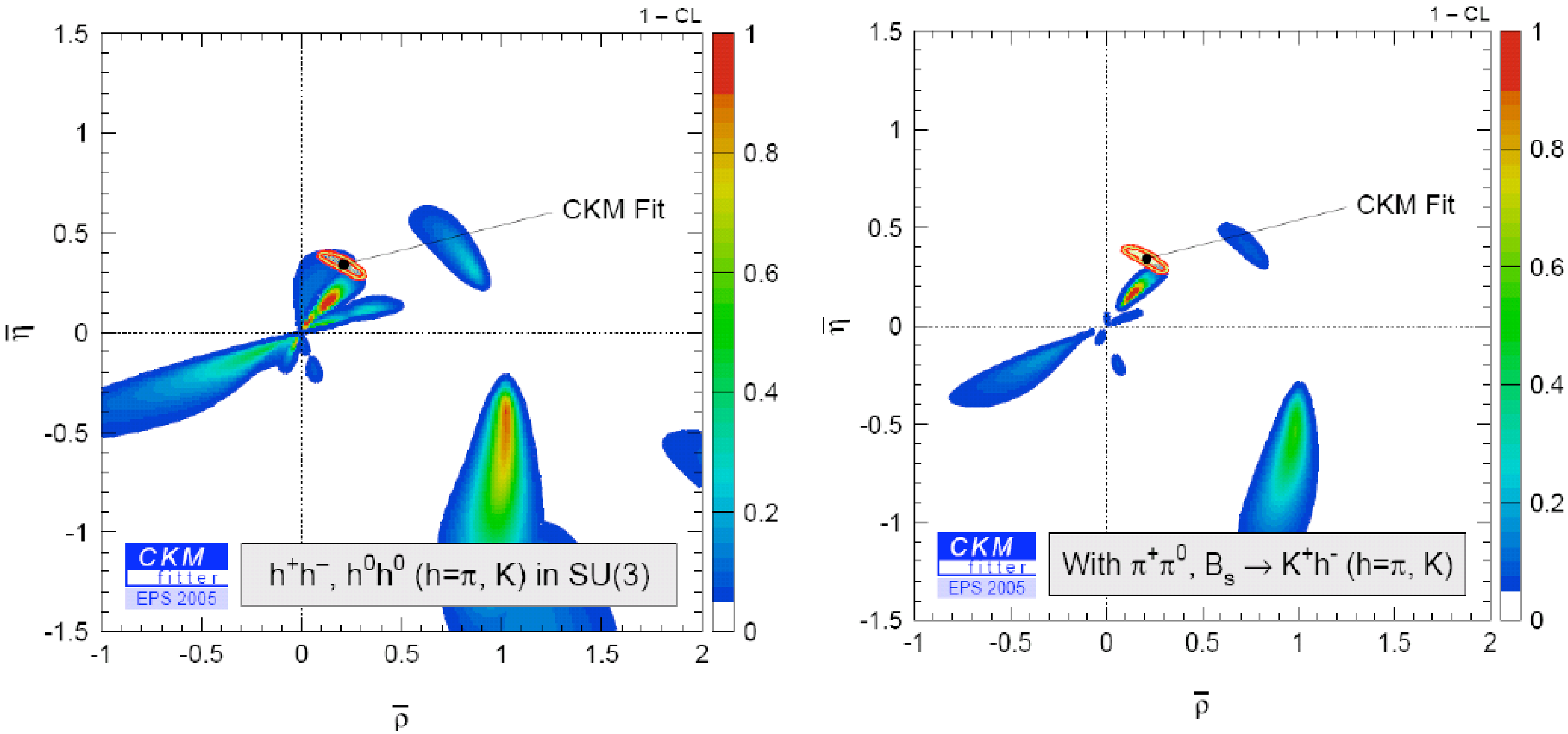
Kπ / KK / ππ SU(3) analysis: amplitudes

"α" →
$$A(K^+\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P$$
$$A(K^0\pi^+) = V_{us}V^*_{ub}N^{0+} + V_{ts}V^*_{tb}(-P + P^{EW}_C)$$
$$\sqrt{2}A(K^+\pi^0) = V_{us}V^*_{ub}(T^{+-} + T^{00} - N^{0+}) + V_{ts}V^*_{tb}(P + P^{EW} - P^{EW}_C)$$
"β" →
$$\sqrt{2}A(K^0\pi^0) = V_{us}V^*_{ub}T^{00} + V_{ts}V^*_{tb}(-P + P^{EW})$$
$$A(\pi^+\pi^-) = V_{ud}V^*_{ub}(T^{+-} + \Delta T) + V_{td}V^*_{tb}(P + PA)$$
$$\sqrt{2}A(\pi^0\pi^0) = V_{ud}V^*_{ub}(T^{00} - \Delta T) + V_{td}V^*_{tb}(-P - PA + P^{EW})$$
$$\sqrt{2}A(\pi^+\pi^0) = V_{ud}V^*_{ub}(T^{+-} + T^{00}) + V_{td}V^*_{tb}P^{EW}$$
$$A(K^+K^-) = V_{ud}V^*_{ub}\Delta T + V_{td}V^*_{tb}PA$$
$$A(K^0\overline{K}^0) = V_{ud}V^*_{ub}\Delta P + V_{td}V^*_{tb}(-P - PA + P^{EW}_C - \frac{1}{3}P^{EW}_{K\overline{K}})$$
$$A(K^+\overline{K}^0) = V_{ud}V^*_{ub}N^{0+} + V_{td}V^*_{tb}(-P + P^{EW}_C)\,.$$

Tevatron (CDF)
$$A(B_s \to K^+K^-) = V_{us}V^*_{ub}(T^{+-} + \Delta T) + V_{ts}V^*_{tb}(P + PA)$$
$$A(B_s \to K^+\pi^-) = V_{ud}V^*_{ub}T^{+-} + V_{td}V^*_{tb}P$$
$$A(B_s \to \pi^+\pi^-) = V_{us}V^*_{ub}\Delta T + V_{ts}V^*_{tb}PA\,.$$

[Malcles,Charles,Ocariz,Hocker - Moriond06]

sub-system "αβ": $B \to \pi^+\pi^-$, $K^+\pi^-$, K^+K^-, $\pi^0\pi^0$, $K_S\pi^0$



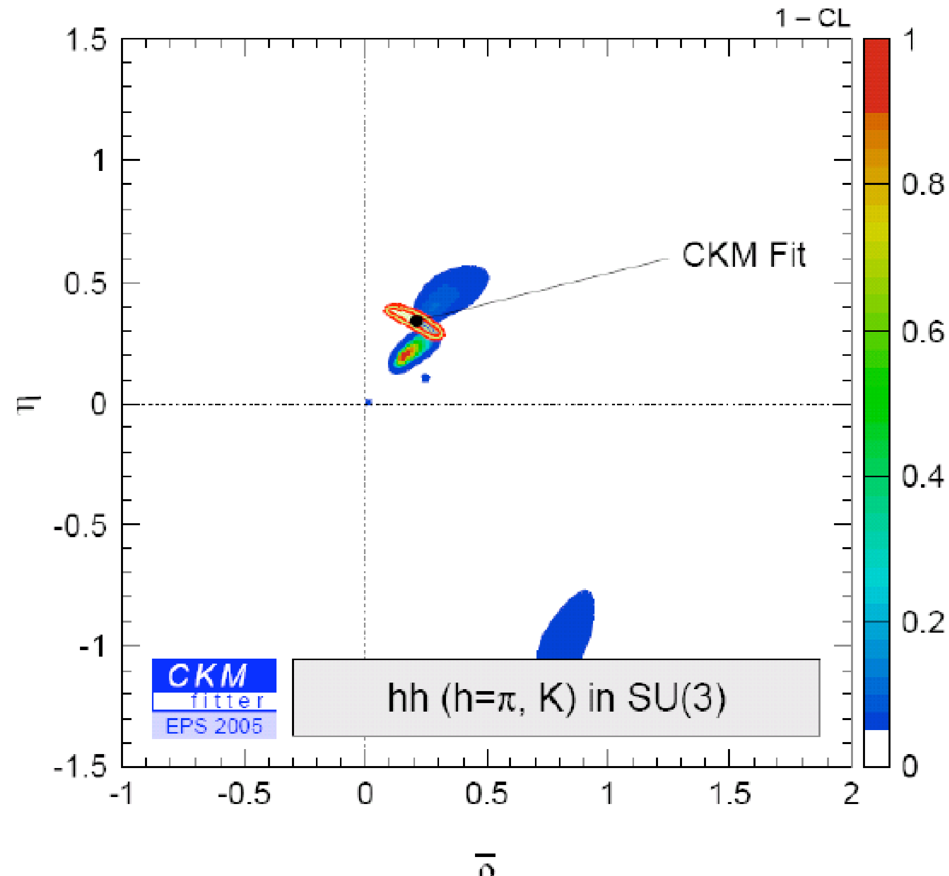
- **Constraints in the (ρ,η) plane stronger than the naïve product "α"×"β"**
- **2 sources of correlations between "α" and "β": K^+K^- and the EWPs**
- **The strong correlation comes mainly from the EWPs: data prefer non standard values of R^+ and R^- i.e. non standard EWPs** (in agreement with what was argued in Buras *et al.* (BFRS), EPJ C32, 45 (2003), Chiang *et al*, PRD D70, 034020 (2004), Gronau and Rosner PLB 572, 43-49 (2003)).
- **But the pValue of the standard parameterization +$(\rho,\eta)_{SM}$ is good >30%**

[Malcles,Charles,Ocariz,Hocker - Moriond06]

With full system of inputs for EPS 2005

With all available inputs:

- Elimination of some of the mirror solutions
- The interesting zone does not change a lot
- Very constraining!
- Good agreement with the SM (pValue > 30%)
- Main contributions to χ^2:
  - $BR(K_s\pi^0)$, $S(K_s\pi^0)$
  - $BR(K^+\pi^-)$
- Better fit obtained with non-standard EWPs

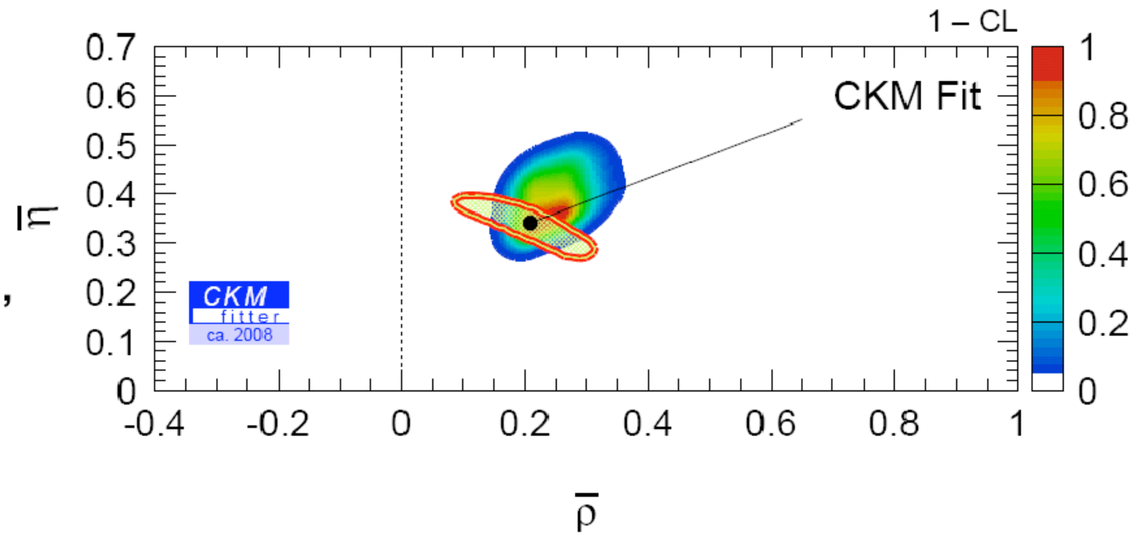


[Malcles,Charles,Ocariz,Hocker - Moriond06]

Full system: ca. 2008

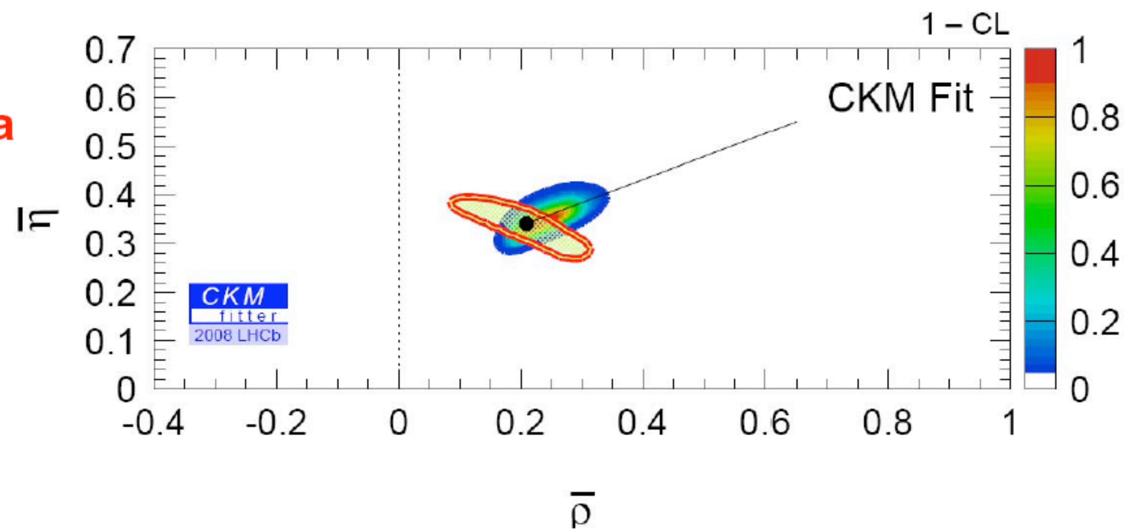
Very constraining!

- **top plot:** B factories (20 inputs) and CDF (6 not independent inputs) only
- **bottom plot:** adding $C(B_s \to K^+ K^-)$, $S(B_s \to K^+ K^-)$, and $C(B_s \to K^+ \pi^-)$



In the future: we expect up to 38 observables for 15 parameters allowing to:

- fit part of SU(3) breaking in a model independent way (for exemple in the amplitudes ratios)
- fit New Physics under SU(3) assumption



[Malcles,Charles,Ocariz,Hocker - Moriond06]

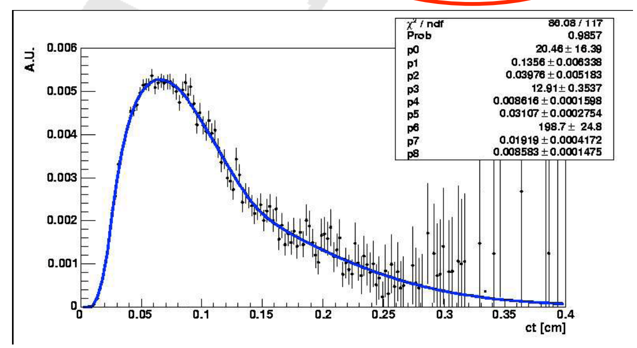
$B^0_s \to K^+K^-$ lifetime analysis

Add lifetime information to the fit of composition:

$$\mathscr{L} \sim \wp^{m}(m_{\pi\pi}|\alpha)\,\wp^{p}(\alpha, p_{\rm tot})\,\wp^{\rm PID}(dE/dx_1, dE/dx_2|\alpha, p_{\rm tot})\,\wp^{\rm life}(ct).$$

$$\wp^{\rm life}(ct) = \exp(ct) \times {\rm Gauss}(ct) \times \varepsilon(ct)$$

decay — detector smearing — trigger bias



Trigger bias for signal is extracted from detailed simulation.

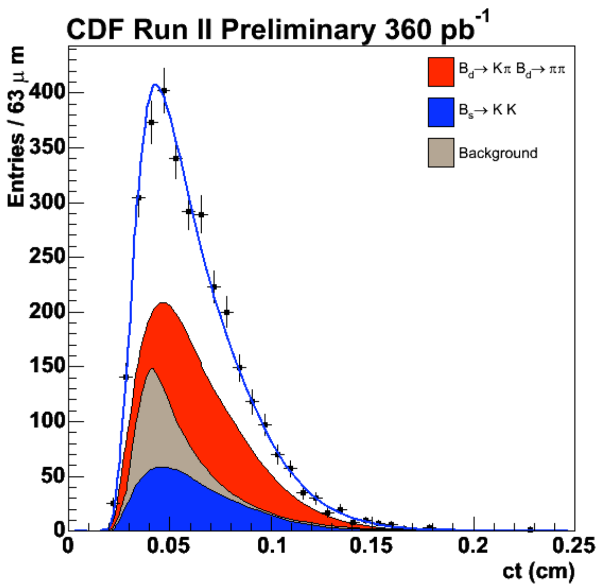
Procedure validated in unbiased $B \to J/\psi X$ decays from dimuon trigger.

Check that lifetime fits of samples with/without applying track-trigger cuts yield consistent results.

Lifetime p.d.f for background is extracted from higher mass data sideband.

$B^0_s \to K^+K^-$ lifetime results (360 pb^{-1})

	$c\tau(B^0)$ [μm]	$c\tau(B^0_s \to K^+K^-)$ [μm]
both free	452 ± 24	463 ± 56
$c\tau(B^0)$ constrained to PDG	–	458 ± 53



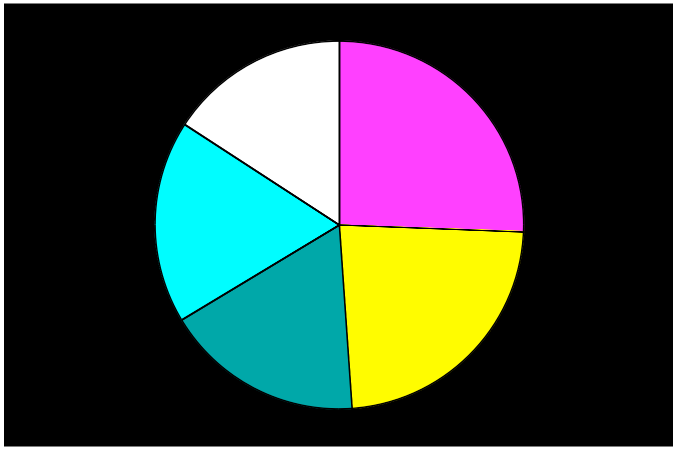
$B^0_s \to K^+K^-$ predicted ~95% CP-even: has the lifetime of "light B^0_s" :

$$\tau_L = 1.53 \pm 0.18\ (stat.) \pm 0.02\ (syst.)\text{ps}$$

Combine with HFAG average $(\tau_L^2 + \tau_H^2)/(\tau_L + \tau_H)$:

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s^{CP}} = -0.08 \pm 0.23\ (stat.) \pm 0.03\ (syst.)$$

Dominant systematics :

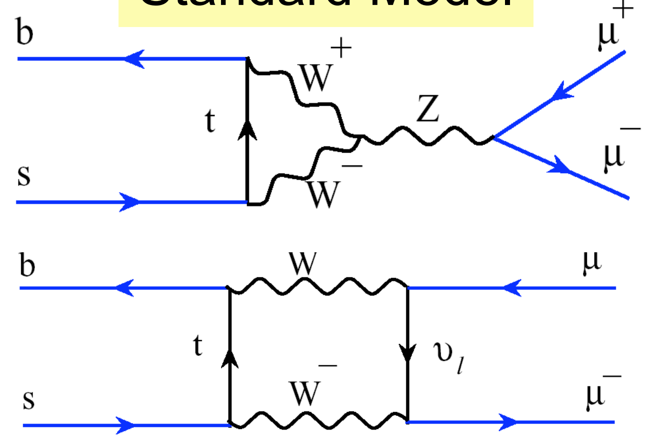


- detector alignment;
- input $p_T(B)$ in simulation;
- lifetime model of background;
- dE/dx model;
- trigger-bias.

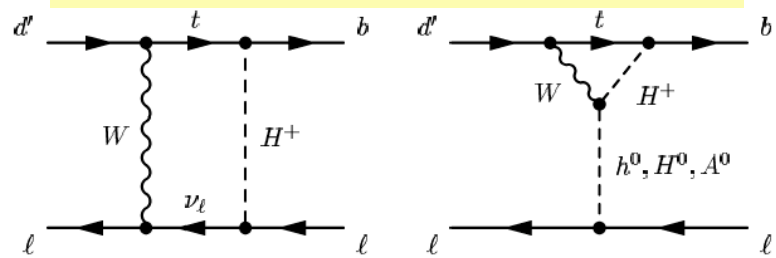
Purely leptonic B decays

- **$B \to l^+ l^-$** decay is helicity suppressed FCNC
- SM: $BR(B_s \to \mu^+\mu^-) \sim 3.4\times10^{-9}$
- depends only on one SM operator in effective Hamiltonian, hadronic uncertainties small
- B_d relative to B_s suppressed by $|V_{td}/V_{ts}|^2 \sim 0.04$ if no additional sources of flavor violation
- particularly sensitive to models w/ extended Higgs sector
  - BR grows ~$\tan^6\beta$ in MSSM
  - 2HDM models ~ $\tan^4\beta$
  - mSUGRA: BR enhancement correlated with shift of $(g-2)_\mu$
- also, testing ground for
  - minimal SO(10) GUT models
  - R_p violating models, contributions at tree level
  - (neutralino) dark matter …
- reaching SM sensitivity: present limit for $B_s \to \mu^+\mu^-$ comes closest to SM value

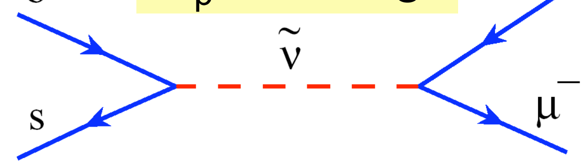
Standard Model



Two-Higgs Doublet models:

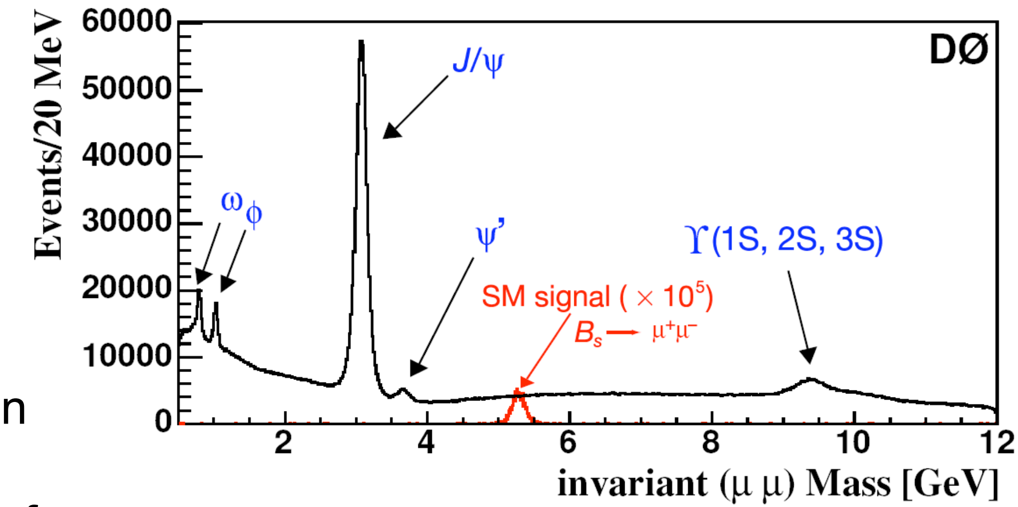


R_p violating:



Experimental search

- **CDF:**
  - 780 pb^{-1} di-muon triggered data
  - two separate search channels
    - central/central muons
    - central/forward muons
  - extract B_s and B_d limit
- **DØ:**
  - 240 pb^{-1} (update 300 pb^{-1}) di-muon triggered data (limit)
  - Combined sensitivity for 700 pb^{-1} of recorded data (300 pb^{-1} + 400 pb^{-1})
- **both experiments:**
  - blind analysis to avoid experimenter's bias
  - side bands for background determination
  - use $B^+ \to J/\psi K^+$ as normalization mode ($J/\psi \to \mu^+\mu^-$ cancels $\mu^+\mu^-$ selection efficiencies)

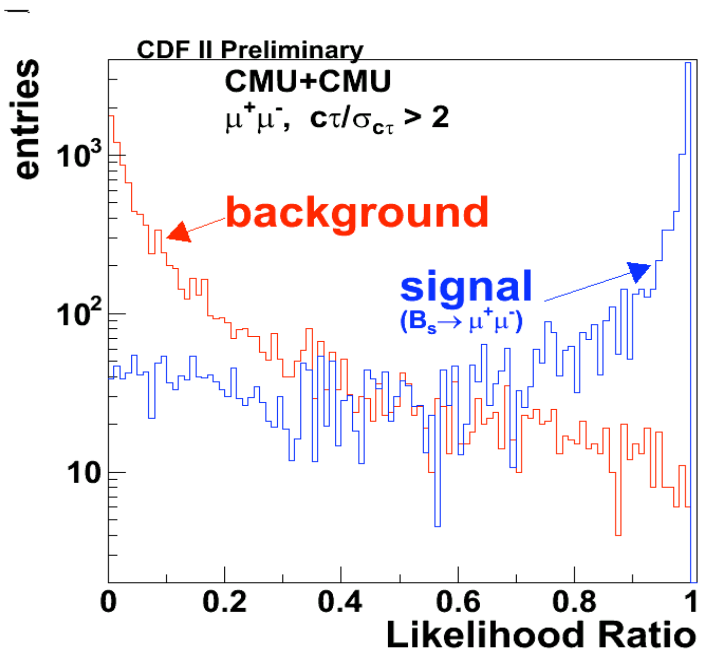


blinded signal region:
DØ: $5.160 < m_{\mu\mu} < 5.520$ GeV/c^2;
±2σ wide, σ=90 MeV
CDF: $5.169 < m_{\mu\mu} < 5.469$ GeV/c^2;
covering B_d and B_s; σ=25 MeV

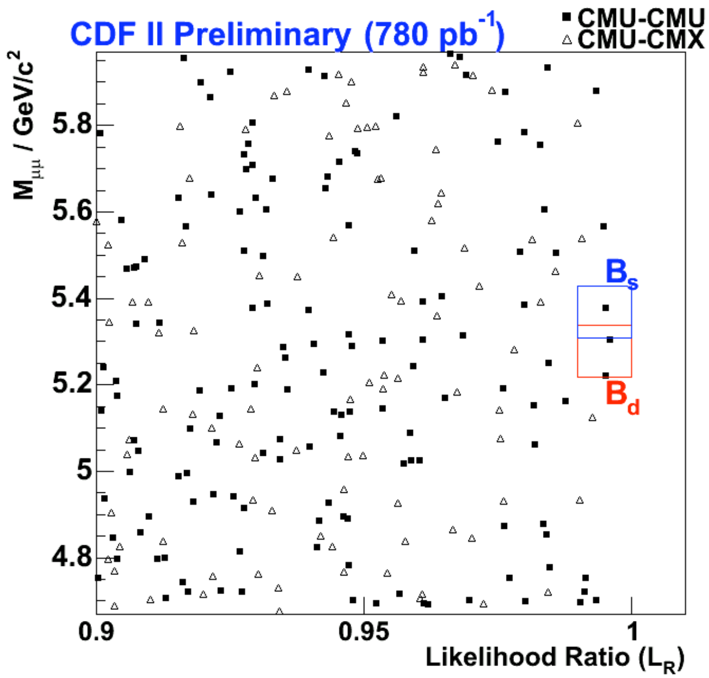
Selection cuts

- **Pre-selection**
  - Mass cuts (D0 has one window for Bs+Bd)
  - $|\eta(\mu)| < 2.0$ (D0) 1.0 (CDF)
  - $p_T(\mu) >$ 2.0 GeV/c (CDF) 2.5 GeV/c (D0)
  - $p_T(B_s$ cand.$) >$ 4.0GeV (CDF) 5.0GeV (D0)
  - good vertex quality
- **Final cuts**
  - CDF:
    - cuts on a Likelihood ratio formed from the variables:M(μμ), proper decay length, pointing angle, and B isolation.
    - Optimizes on average expected Bayesian limit
  - D0:
    - Cuts on 3 variables: Pointing angle, Lxy, B Isolation
    - Optimizes on $\varepsilon/(1.0 + \sqrt{B})$

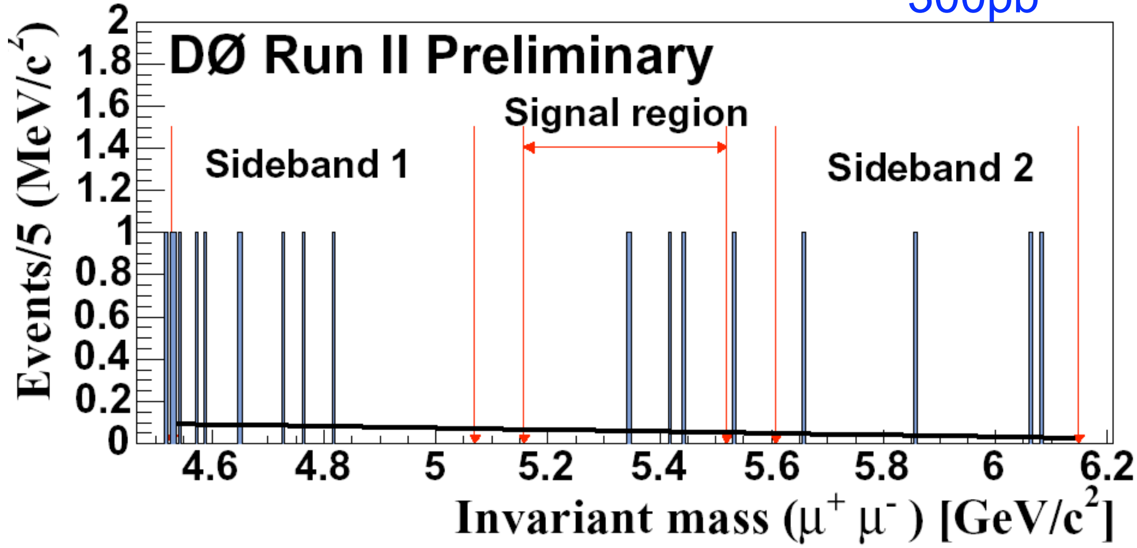
Potential backgrounds:
- continuum μμ Drell-Yan
- sequential b->c->s decays
- double semi-leptonic bb-> μμX
- b/c->μx+fake
- fake + fake



Event count in signal region



300pb^{-1}



- CDF:
  - central/central: observe 1, expect 0.88 ± 0.30
  - Central/forward: observe 0, expect 0.39 ± 0.21
- DØ (300 pb^{-1}):
  - observe 4, expect 4.3 ± 1.2

Backgrounds (CDF)

	B_s^0 Signal Window		B_d^0 Signal Window	
Bkg Source	CMU-CMU	CMU-CMX	CMU-CMU	CMU-CMX
Combinatoric	0.72 ± 0.29	0.36 ± 0.21	0.72 ± 0.29	0.36 ± 0.21
$B \to h^+h^-$	0.16 ± 0.06	0.03 ± 0.01	1.14 ± 0.16	0.23 ± 0.04
Total	0.88 ± 0.30	0.39 ± 0.21	1.86 ± 0.34	0.59 ± 0.21

The present (individual) limits

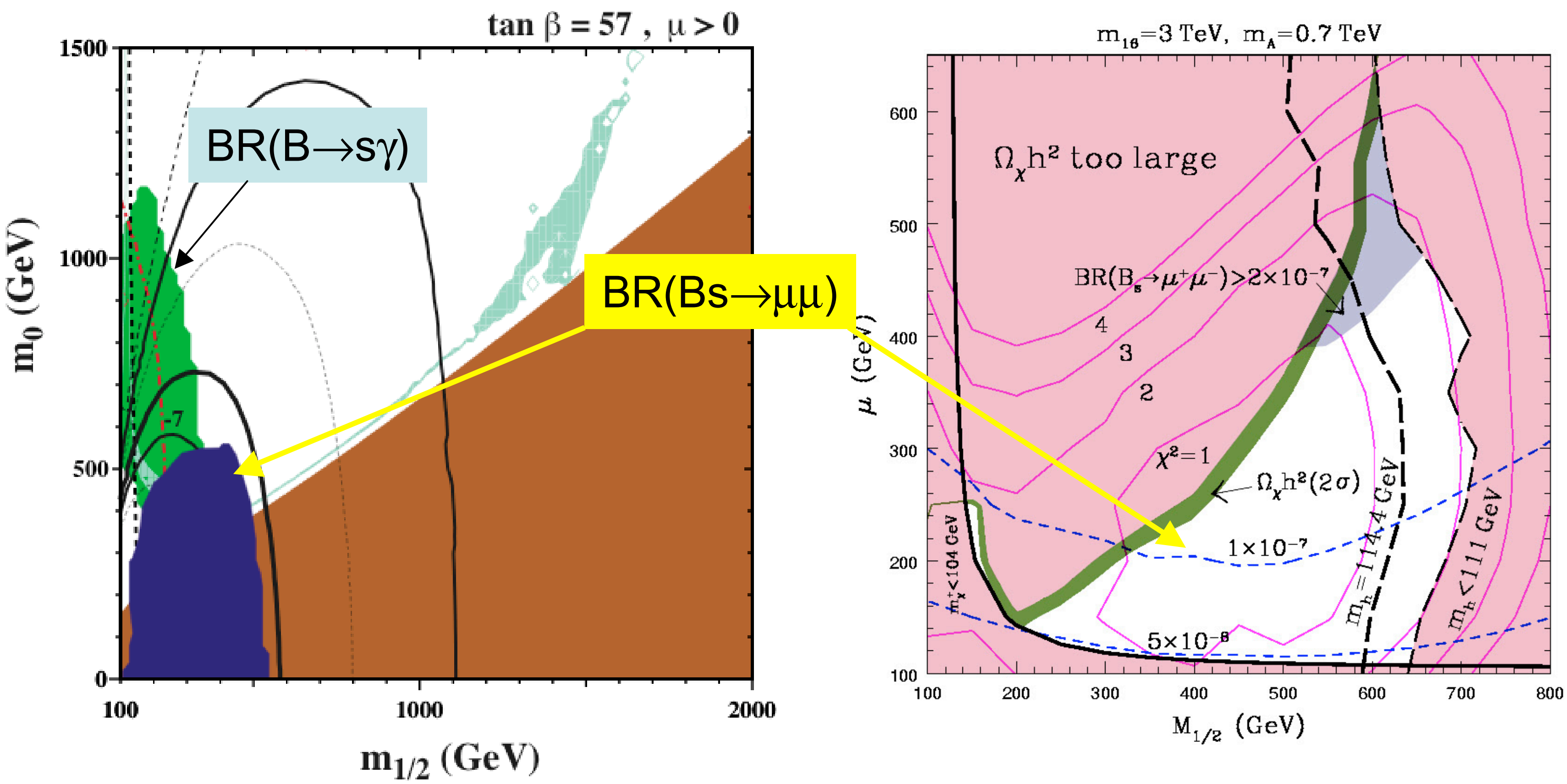
- DØ mass resolution is not sufficient to separate B_s from B_d. Assume no B_d contribution (conservative)
- CDF sets separate limits on B_s & B_d channels
- all limits below are 95% C.L. Bayesian incl. sys. error, DØ also quotes FC limit

CDF $B_s \to \mu\mu$	176 pb^{-1}	7.5_10^{-7}	Published
DØ $B_s \to \mu\mu$	240 pb^{-1}	5.1_10^{-7}	Published
DØ $B_s \to \mu\mu$	300 pb^{-1}	4.0_10^{-7}	Prelim.
DØ <$B_s \to \mu\mu$>	700 pb^{-1}	<2.3_10^{-7}>	Prelim. Sensitivity
CDF $B_s \to \mu\mu$	364 pb^{-1}	2.0_10^{-7}	Published
CDF $B_s \to \mu\mu$	780 pb^{-1}	1.0_10^{-7}	Prelim.
CDF $B_d \to \mu\mu$	364 pb^{-1}	4.9_10^{-8}	Published
CDF $B_d \to \mu\mu$	780 pb^{-1}	3.0_10^{-8}	Prelim.

B_d limit x3 better than published Babar limit w/ 111 fb^{-1}

Constraints on SUSY

CMSSM | **SO(10)**

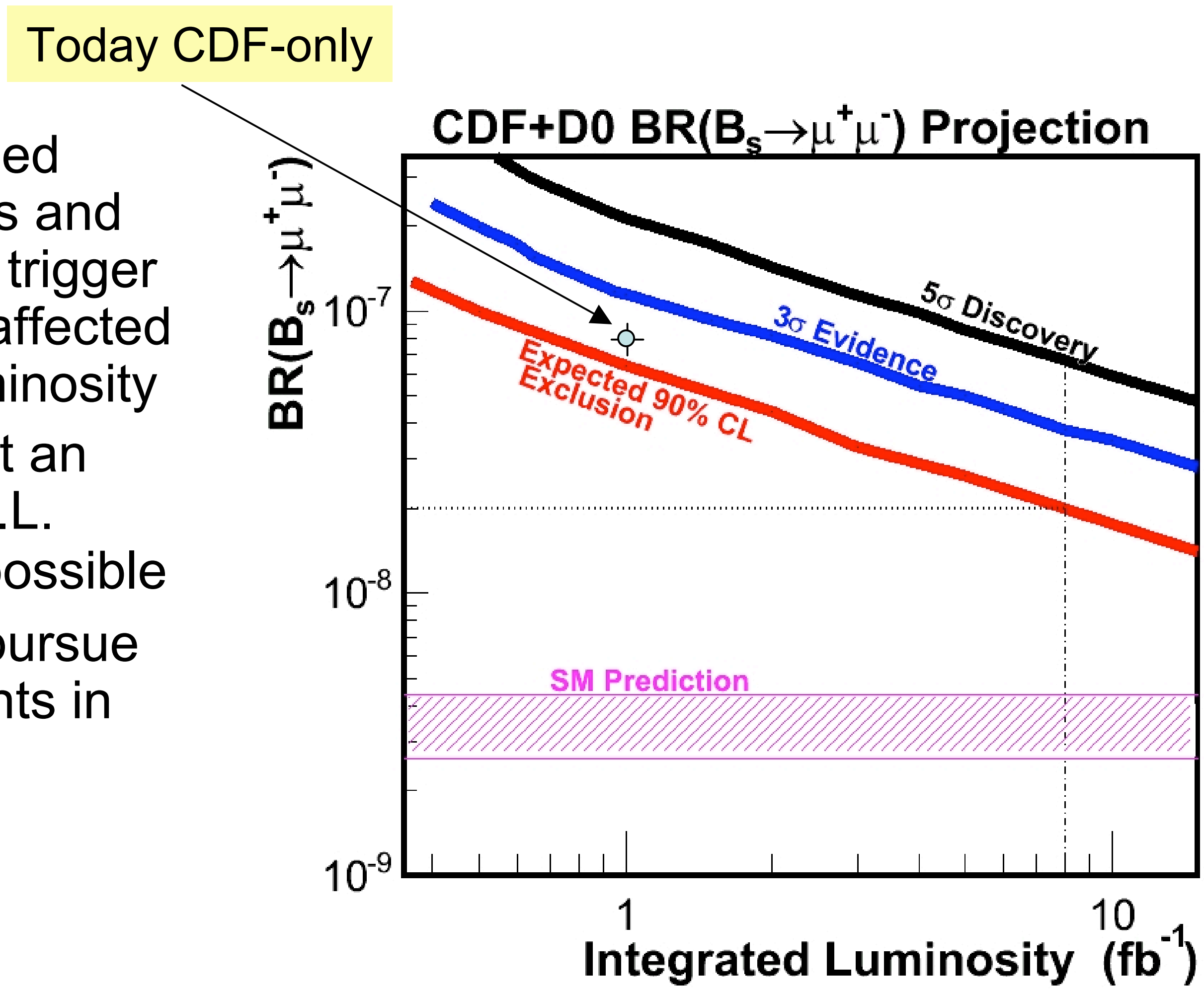


J. Ellis *et al.*, Phys.Lett. B624, 47 2005

R. Dermisek *et al.*, hep-ph/0507233 (2005)

Future Prospects for B_s-> $\mu^+\mu^-$

- assuming unchanged analysis techniques and reconstruction and trigger efficiencies are unaffected with increasing luminosity
- for $8fb^{-1}$/experiment an exclusion at 90%C.L. down to 2×10^{-8} is possible
- both experiments pursue further improvements in their analysis



B_s mixing

B_s Mixing

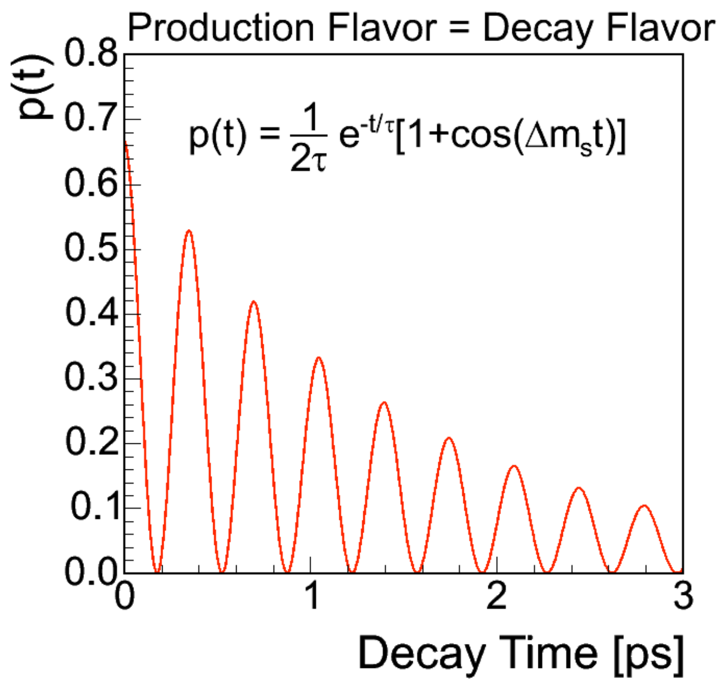
- Neutral B Meson system

$$|B>= (\bar{b}s);\ |\overline{B}>= (b\bar{s})$$

mixture of two mass eigenstates (No CP violation case):

$$|B_H\rangle = \frac{1}{\sqrt{2}}\left(|B\rangle + |\overline{B}\rangle\right)$$

$$|B_L\rangle = \frac{1}{\sqrt{2}}\left(|B\rangle - |\overline{B}\rangle\right)$$



- B_H and B_L may have different mass and decay width
  - $\Delta m = M_H - M_L$ (>0 by definition)
  - $\Delta\Gamma = \Gamma_H - \Gamma_L$

- The case of $\Delta\Gamma = 0$

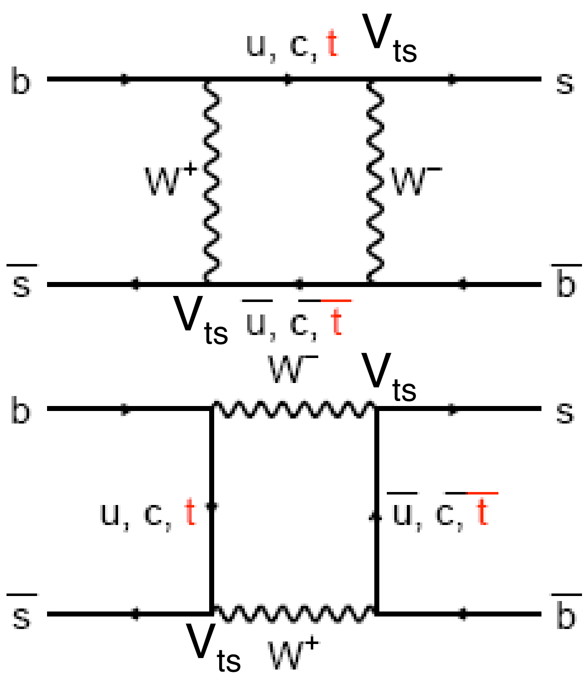
$$p(B \to B) = \frac{e^{-t/\tau}}{2\tau}(1 + \cos\Delta mt)$$

$$p(B \to \overline{B}) = \frac{e^{-t/\tau}}{2\tau}(1 - \cos\Delta mt)$$

Standard Model Prediction

CKM Matrix — Wolfenstein parameterization

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$



Ratio of frequencies for B^0 and B_s

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \frac{f_{Bs}^2 B_{Bs}}{f_{Bd}^2 B_{Bd}} \frac{|V_{ts}|^2}{|V_{td}|^2} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$

$\xi = 1.210\,^{+0.047}_{-0.035}$ from lattice QCD

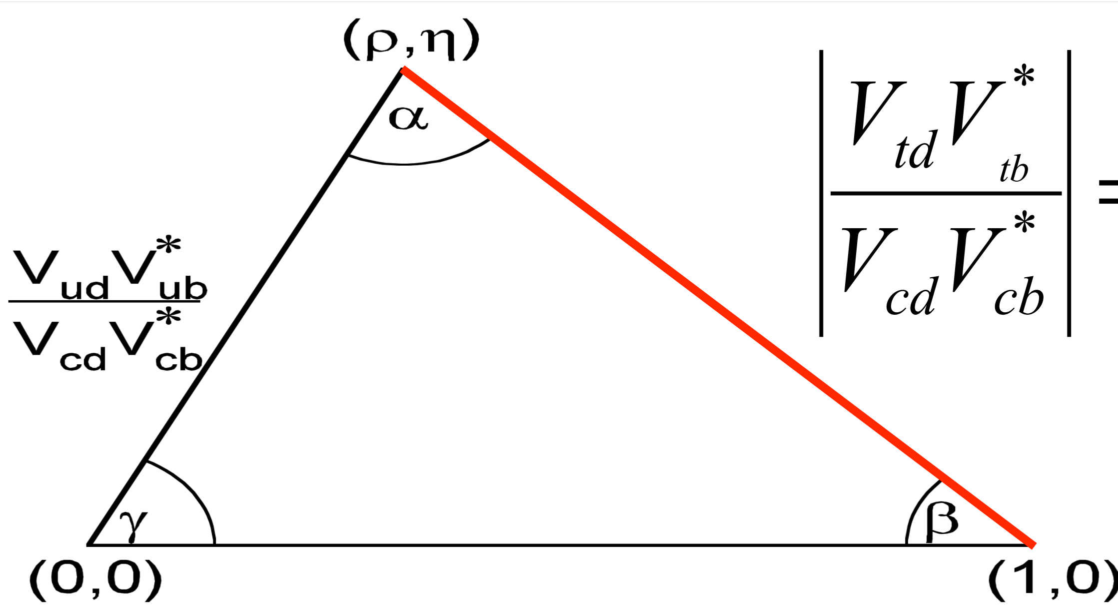
(hep/lat-0510113)

$V_{ts} \sim \lambda^2$, $V_{td} \sim \lambda^3$, $\lambda = 0.224 \pm 0.012$

Unitarity Triangle

CKM Matrix Unitarity Condition

$$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$$

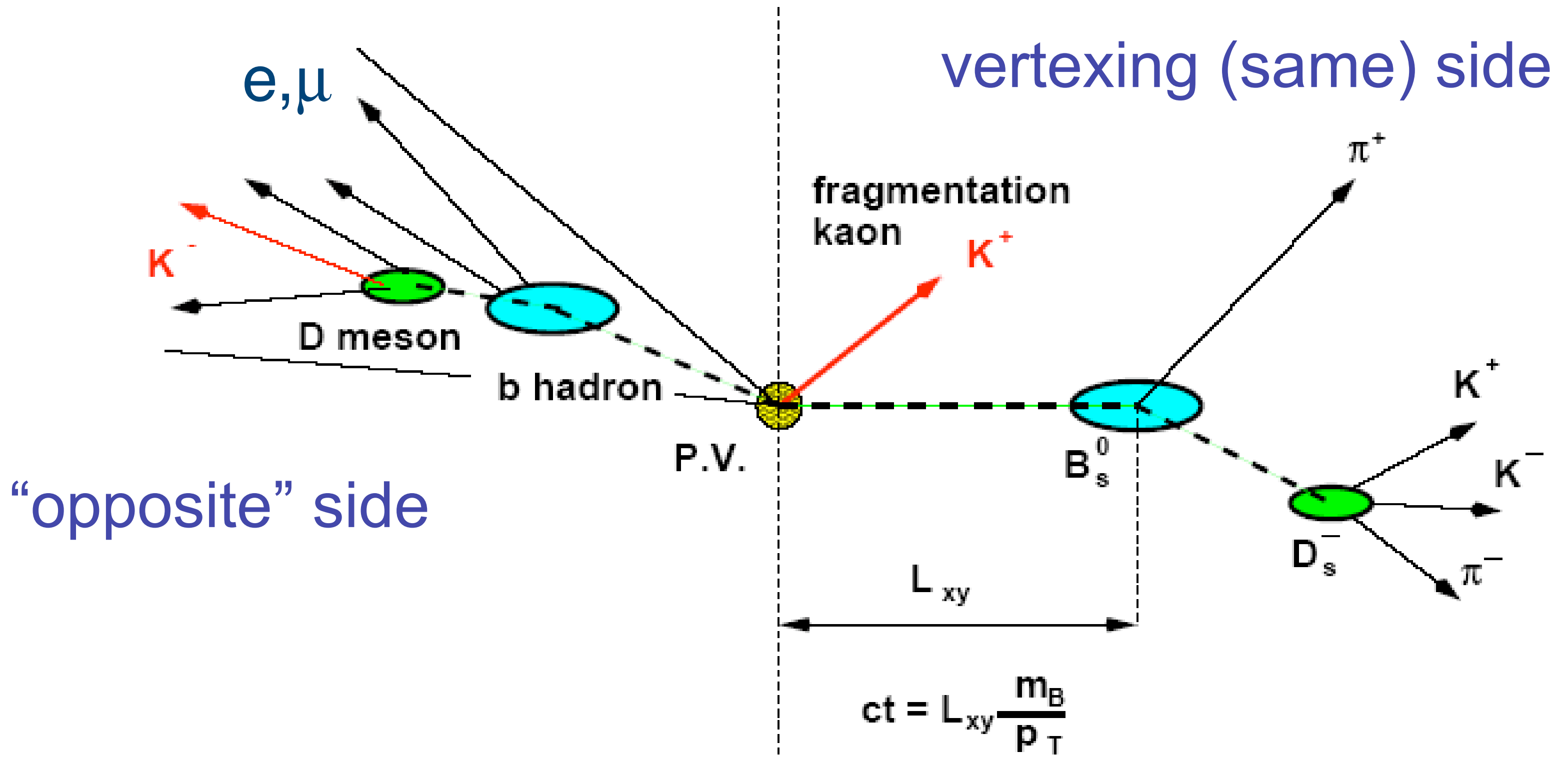


$$\left|\frac{V_{td}V^*_{tb}}{V_{cd}V^*_{cb}}\right| = \frac{|V_{td}|}{|V_{ts}|} \times \frac{1}{|V_{cd}|}$$

$$\frac{|V_{td}|}{|V_{ts}|} \sim \sqrt{\frac{\Delta m_d}{\Delta m_s}}$$

Measurement Principle

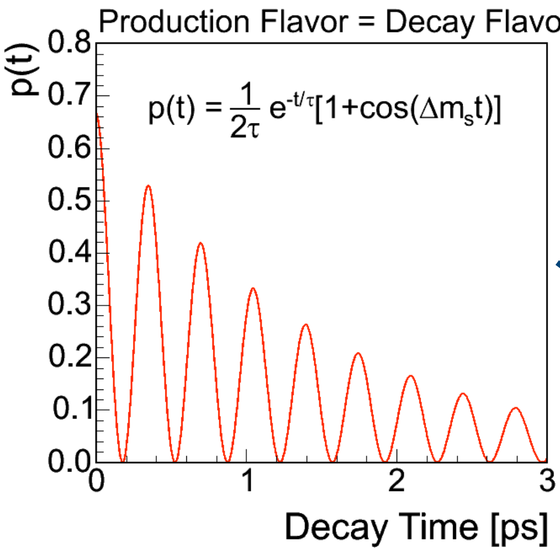
The "Big" Picture



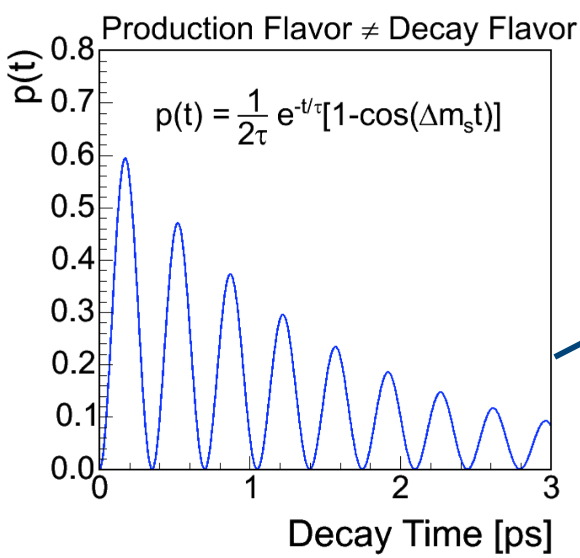
- reconstruct B_s decays ⇒ decay flavor from decay products
- measure proper time of the decay (very precisely)
- infer B_s production flavor (production flavor tagging)

Measurement .. In a Perfect World

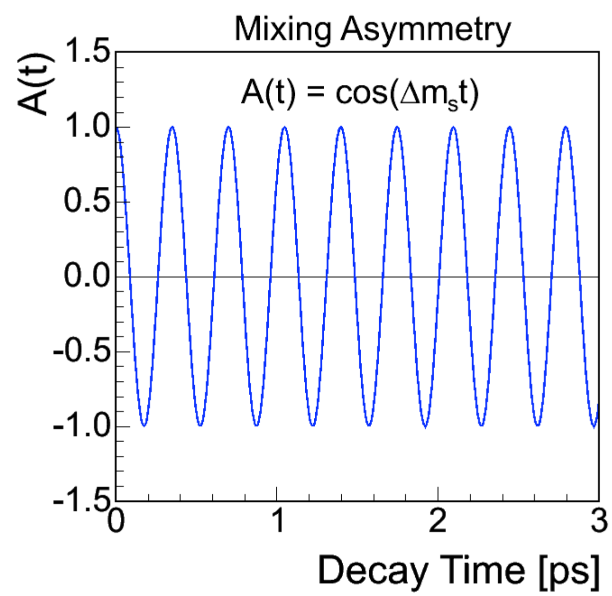
"Right Sign"



"Wrong Sign"

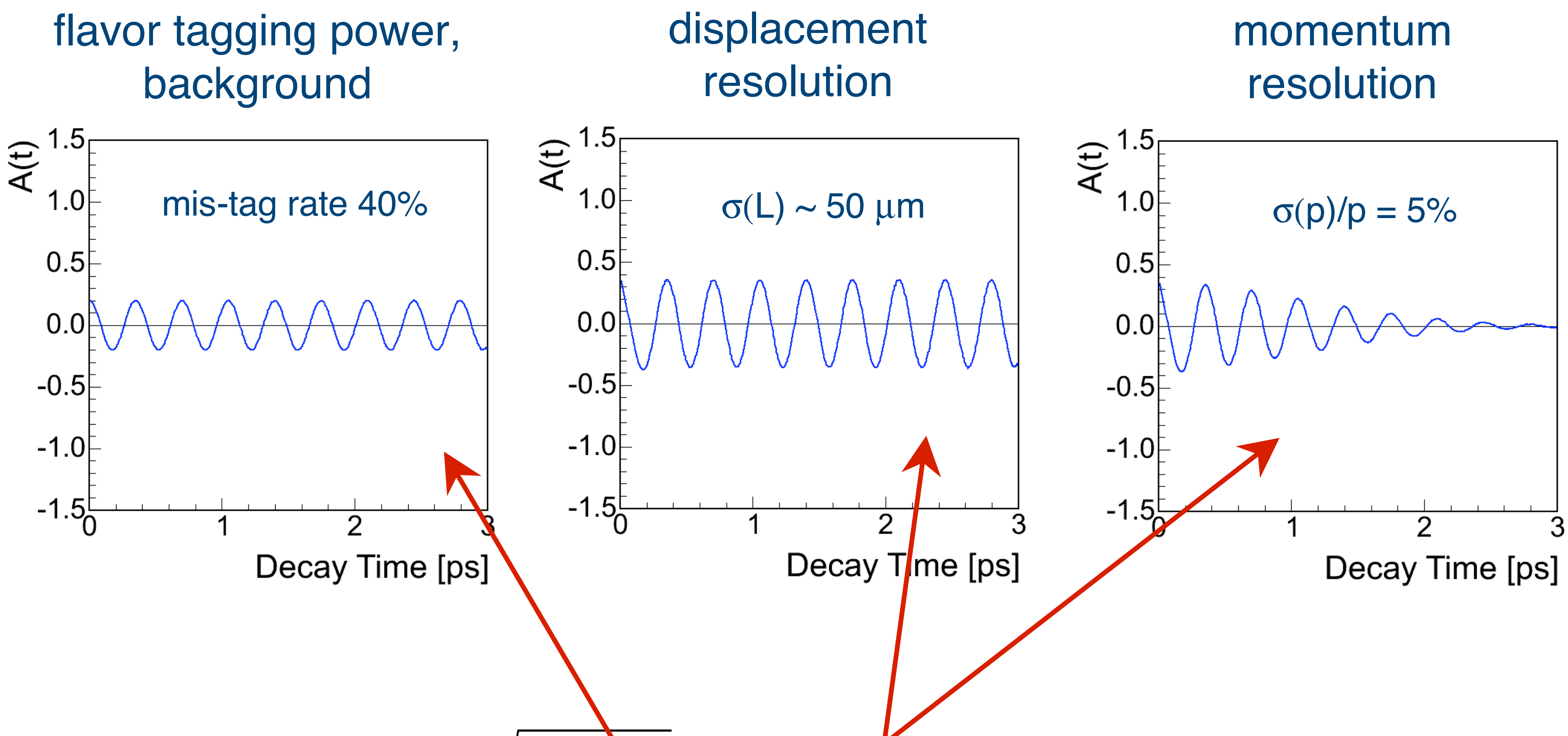


$$A(t) = \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$$



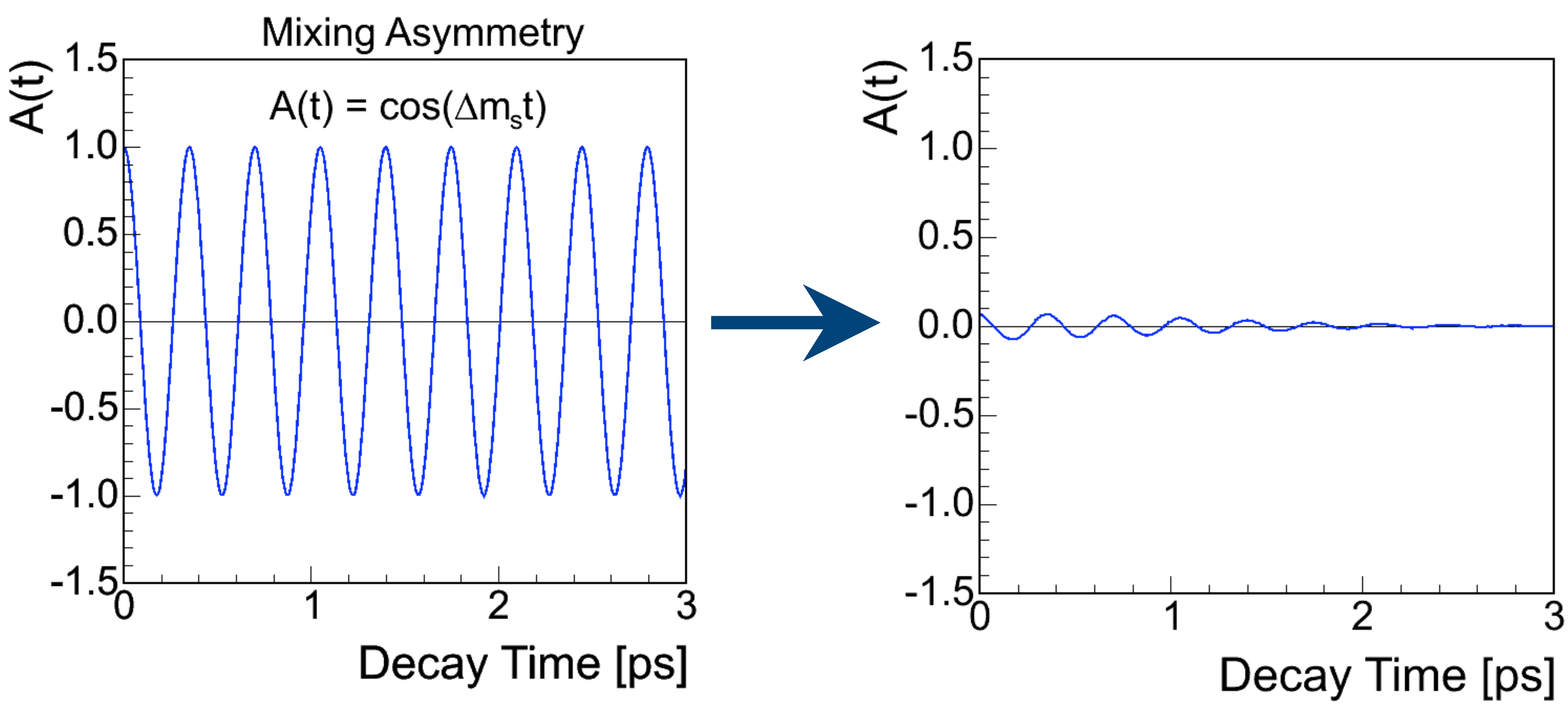
what about detector effects?

Realistic Effects



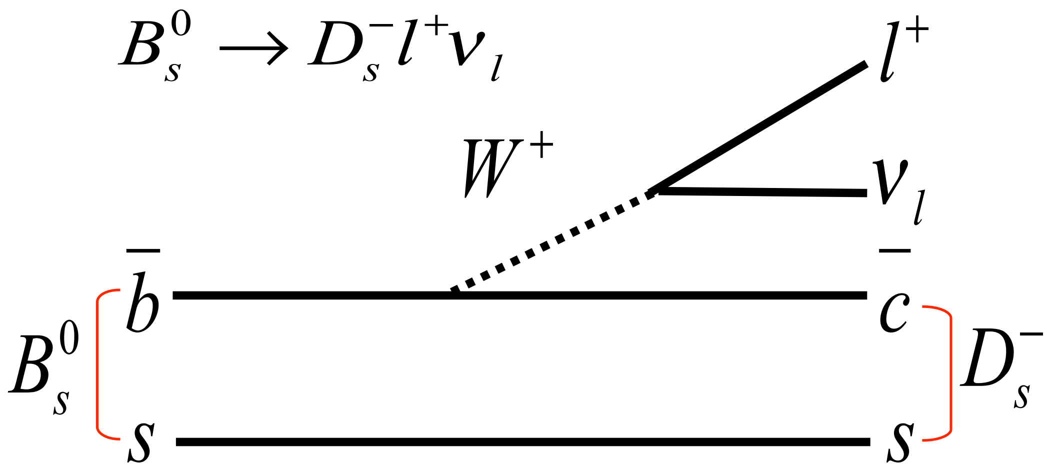
$$\frac{1}{\sigma} = \sqrt{\frac{S\epsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

All Effects Together



Samples of B_s Decays

Semileptonic B_s Decays

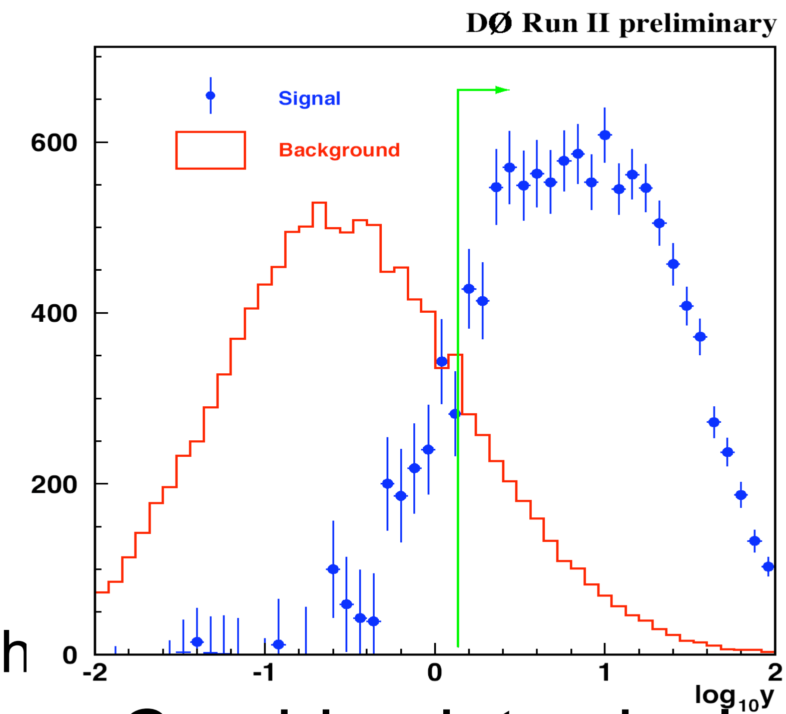


- relatively large signal yields (several 10’s of thousands)
- correct for missing neutrino momentum on average
- loss in proper time resolution
- superior sensitivity in lower Δm_s range

D0 Signal Selection

- Use likelihood ratio method
  - Set of discriminating variables x_i constructed for each event
    - Helicity Angle (D_s,K_1)
    - μD_s Isolation
    - $p_T(K_1K_2)$
    - $m(\mu D_s)$
    - χ^2 of D_s Vertex Fit
    - $m(K_1K_2$ or $K_1\pi)$
  - Construct likelihood ratio for each variable
    - bgrd from $m(D_s)$ sidebands
    - signal from bgrd-sub peak

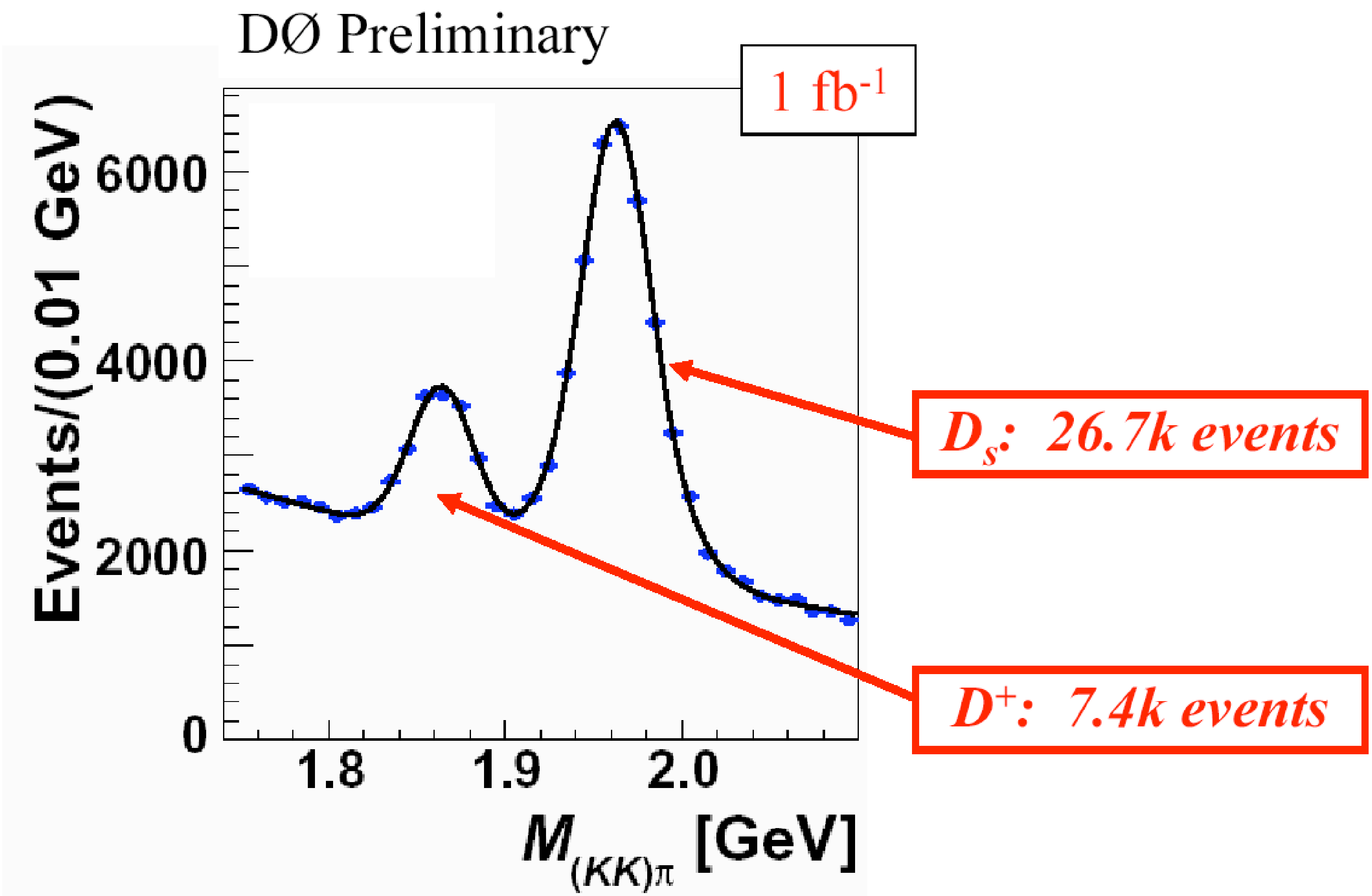
$$y_i = \frac{f_i^S(x_i)}{f_i^B(x_i)}$$



- Combine into single variable
  - Use for final selection

$$Y = \prod_i^n y_i$$

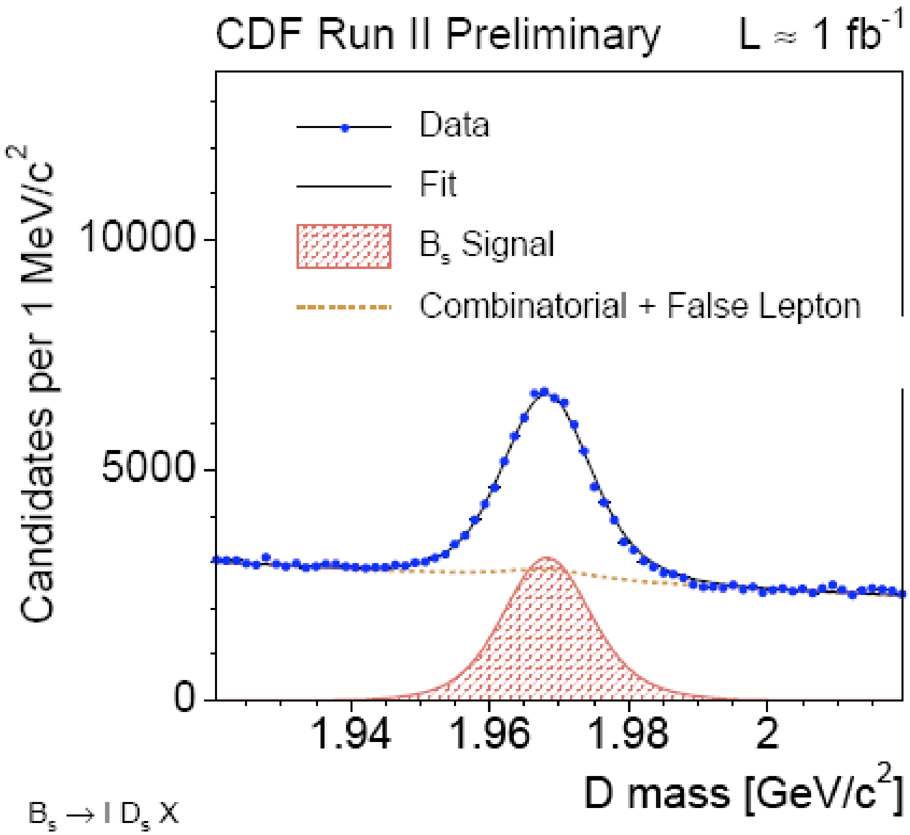
D0 Semileptonic Samples: $D_s^- l^+ X$



CDF signals: the trigger

- Many variations to optimize yield with luminosity
- Hadronic decays (typical selection):
  - L1:
    - 2 tracks – opp. charge – p_T> 2 GeV – $p_{t1}+p_{t2}$ >5.5 GeV - $\delta\phi$ <135°
  - L2:
    - Match to SVT tracks with d > 120 μm – L_{xy} > 200 μm
  - L3: confirm L2 with full offline accuracy
- Semileptonic decays (typical selection);
  - Most leptonic decays from hadronic trigger above
  - L1: e or μ with p_T > 4 GeV + 2 GeV p_T track - $\delta\phi$ < 100°
  - L2: match track to SVT – d > 120 μm - 2° < $\delta\phi$ < 100°
  - L3: confirm L2 with full offline accuracy

CDF Semileptonic Samples: $D_s^- l^+ X$

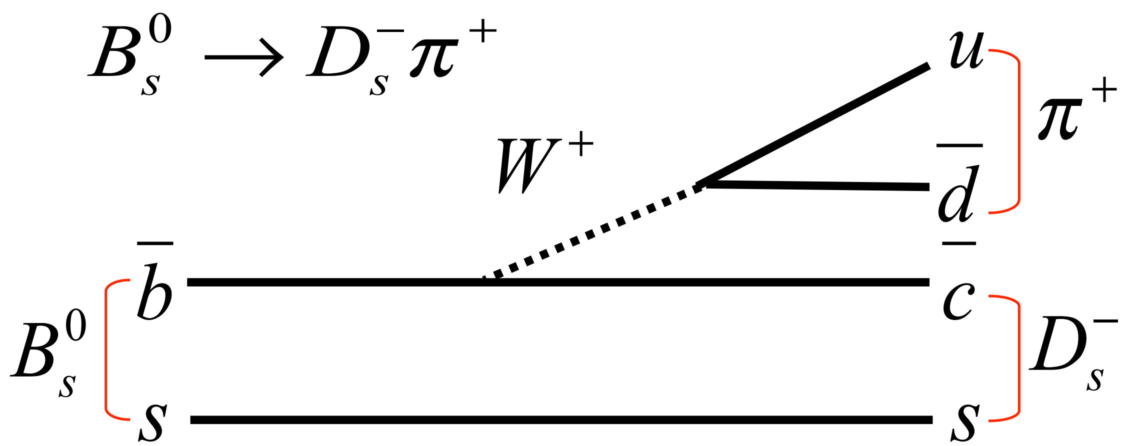


~53 K events

$l\,D_s$: $D_s \to \phi\pi$	32 K
$l\,D_s$: $D_s \to K^*K$	11 K
$l\,D_s$: $D_s \to \pi\pi\pi$	10 K

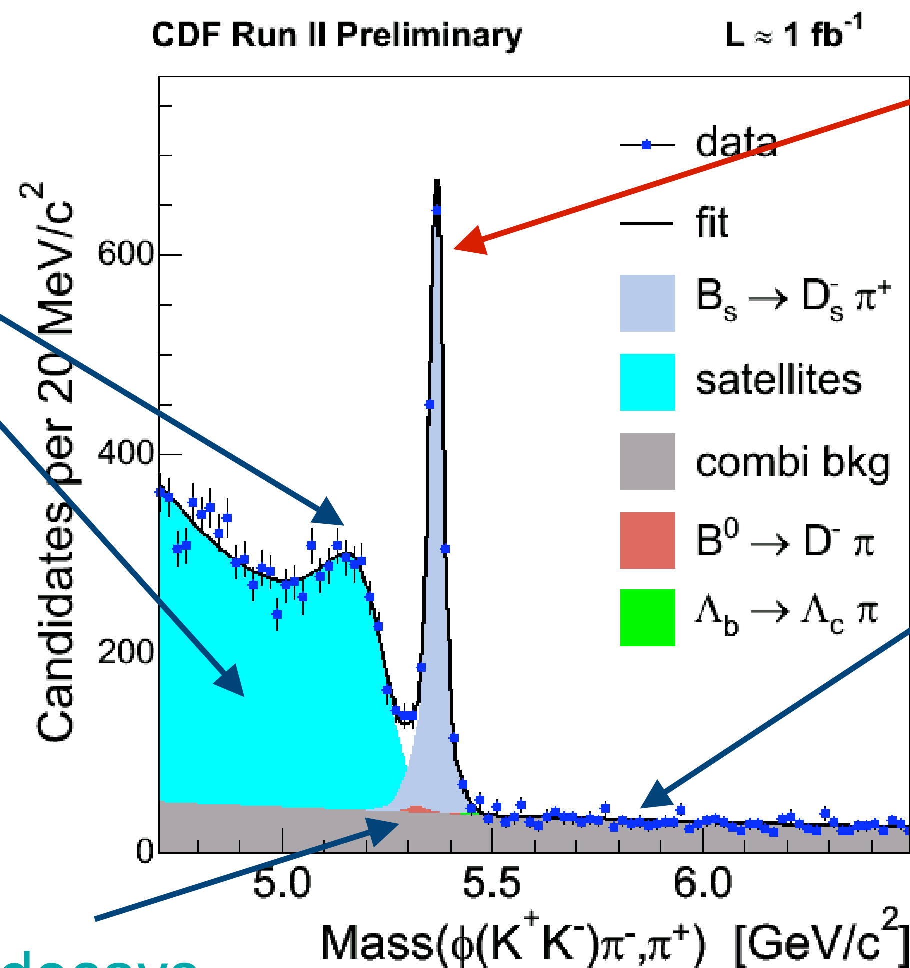
$l\,D^0$: $D^0 \to K\pi$	540 K
$l\,D^{*-}$: $D^0 \to K\pi$	75 K
$l\,D^-$: $D^- \to K\pi\pi$	300 K

Hadronic B_s Decays (CDF only)



- need hadronic trigger: 2 tracks with impact parameter
- relatively small signal yields (few thousand decays)
- momentum completely contained in tracker
- superior sensitivity at higher Δm_s

Example Mass Spectrum



partially reconstructed B mesons (satellites)

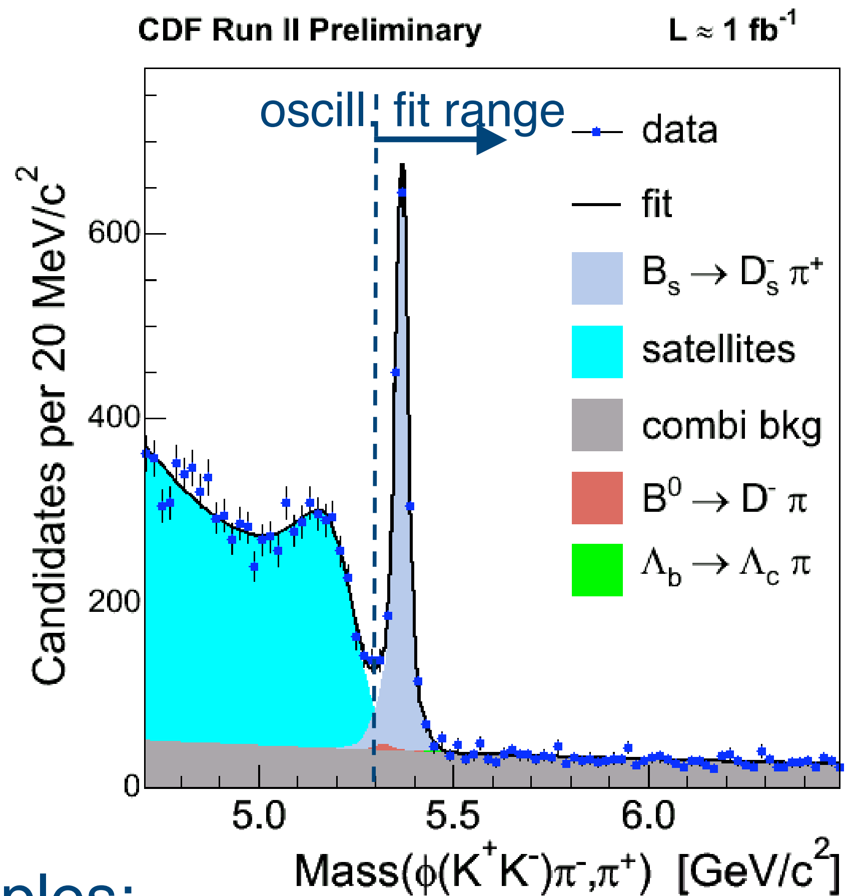
signal $B_s \to D_s\pi$, $D_s \to \phi\pi$, $\phi \to K^+K^-$

combinatorial background

$B^0 \to D^-\pi$ decays

Signal Yield Summary: Hadronic

	Yield
$B_s \rightarrow D_s\pi$ ($\phi\pi$)	1600
$B_s \rightarrow D_s\pi$ ($K^* K$)	800
$B_s \rightarrow D_s\ \pi$ (3π)	600
$B_s \rightarrow D_s 3\pi$ ($\phi\ \pi$)	500
$B_s \rightarrow D_s 3\pi$ (K^*K)	200
Total	3700

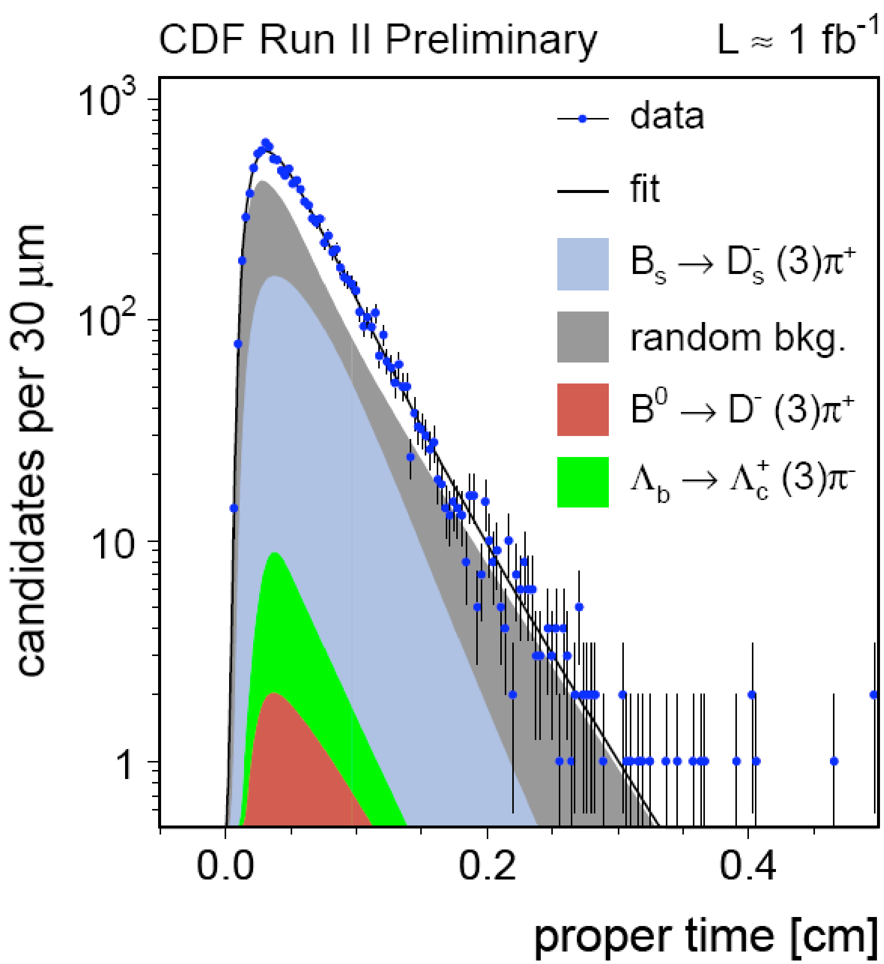


High statistics light B meson samples:

B^+ ($D^0\pi^+$): 26k events

B^0 ($D^-\pi$): 22k events

Hadronic Lifetime Results



Mode	Lifetime [ps] (stat. only)
$B^0 \to D^- \pi^+$	1.508 ± 0.017
$B^- \to D^0 \pi^-$	1.638 ± 0.017
$B_s \to D_s \pi(\pi\pi)$	1.538 ± 0.040

World Average:

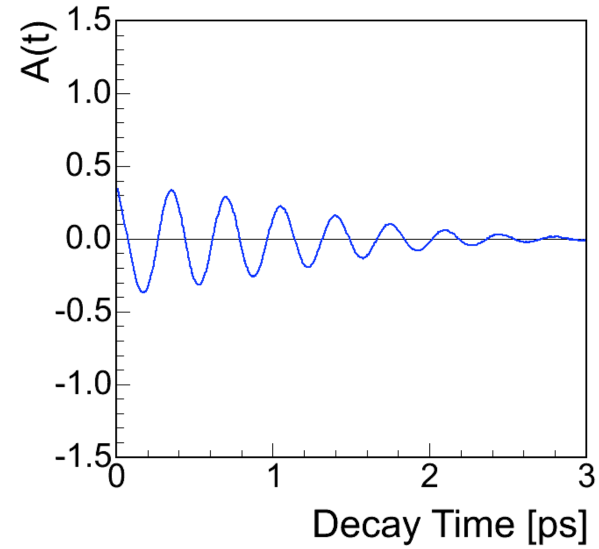
B^0 : 1.534 ± 0.013 ps^{-1}
B^+ : 1.653 ± 0.014 ps^{-1}
B_s : 1.469 ± 0.059 ps^{-1}

Excellent agreement!

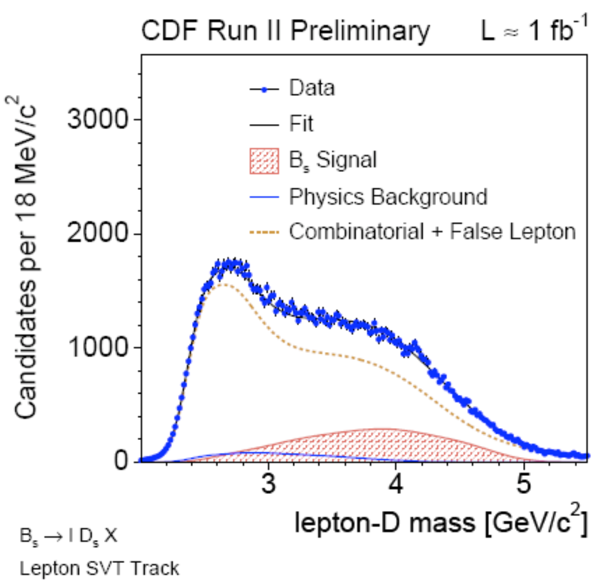
Semileptonic Lifetime Measurement

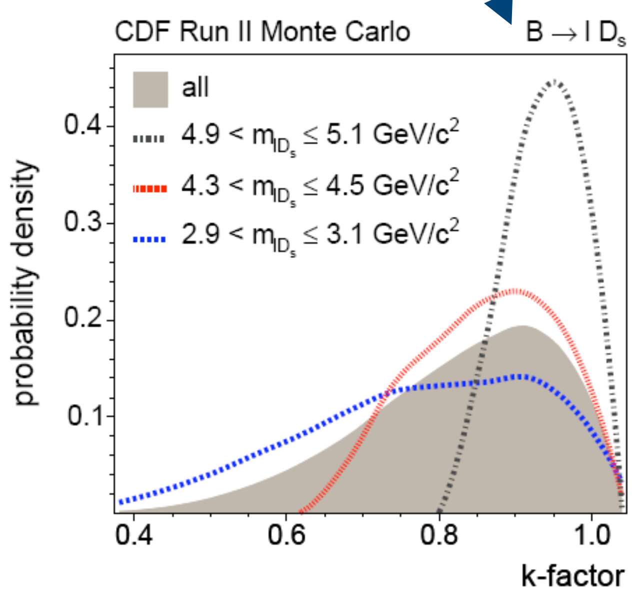
- neutrino momentum not reconstructed

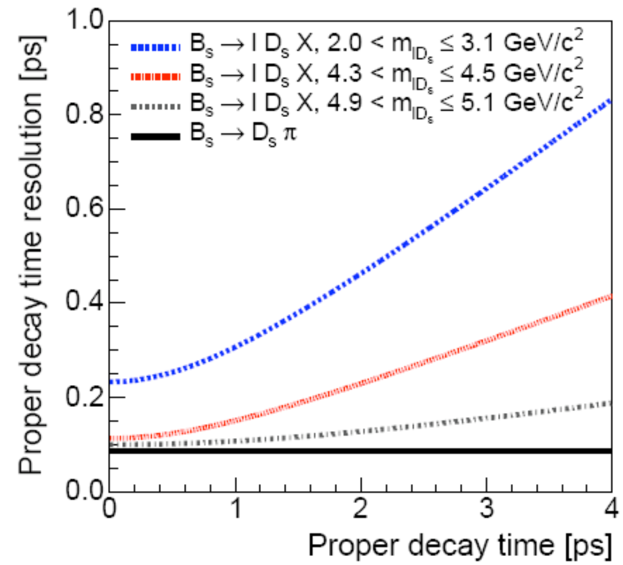
$$K = \frac{p_T(lD)}{p_T(B)} \cdot \frac{L(B)}{L(lD)}$$



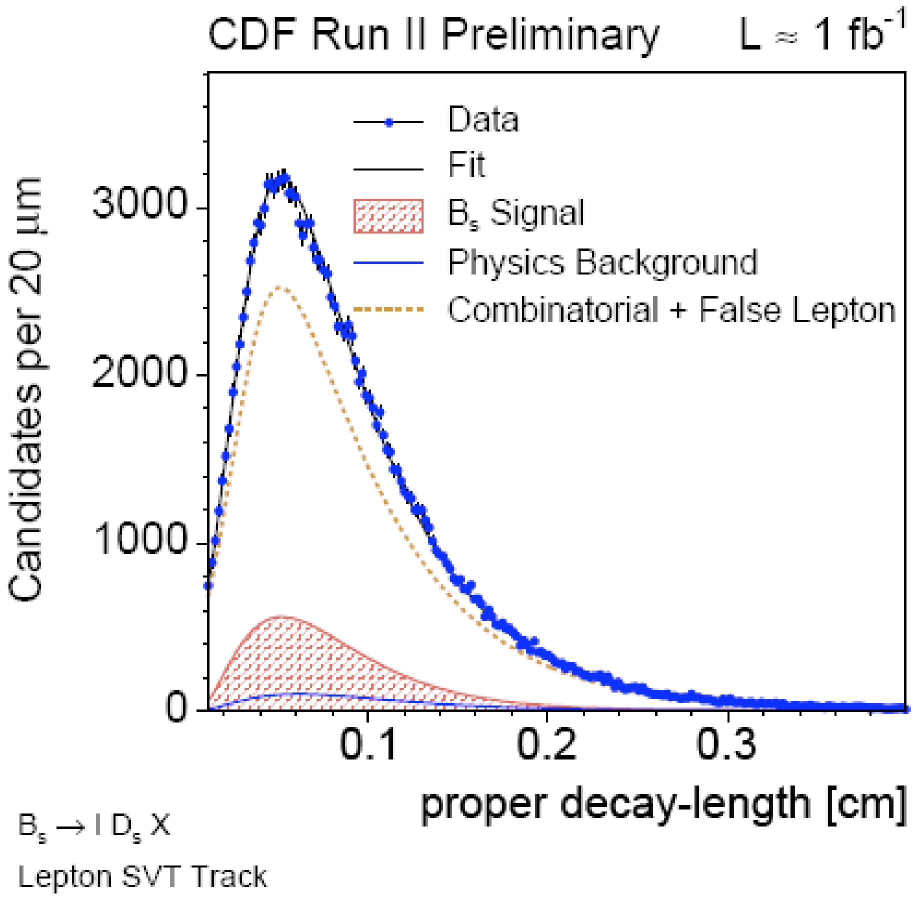
- correct for neutrino on average



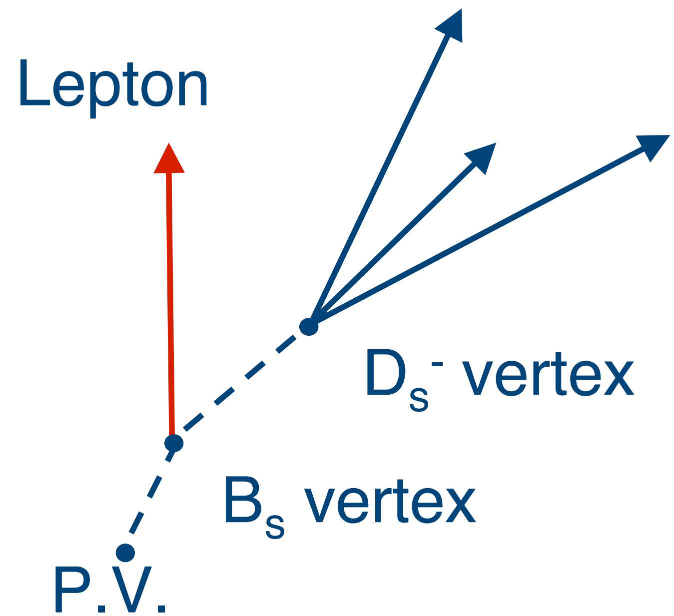




lD_s ct* Projections



$$ct^* = \frac{L(lD) \cdot m(B)}{p_T(lD)}$$



B_s lifetime in 355 pb^{-1}: 1.48 ± 0.03 (stat) ps

World Average value: 1.469 ± 0.059 ps

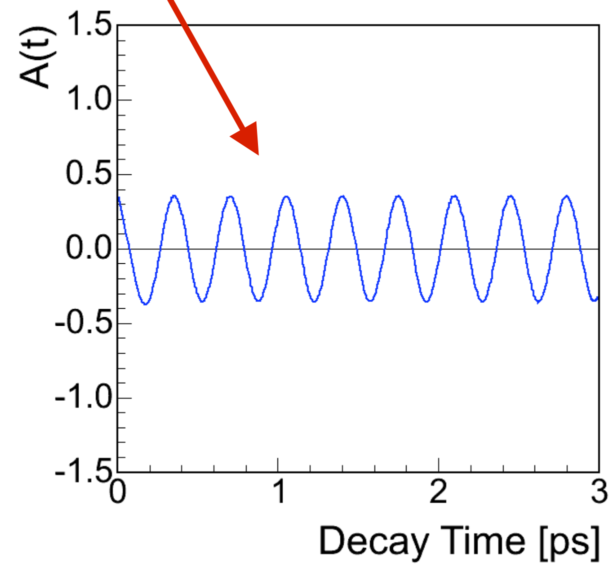
Proper Time Resolution

Proper Time Resolution

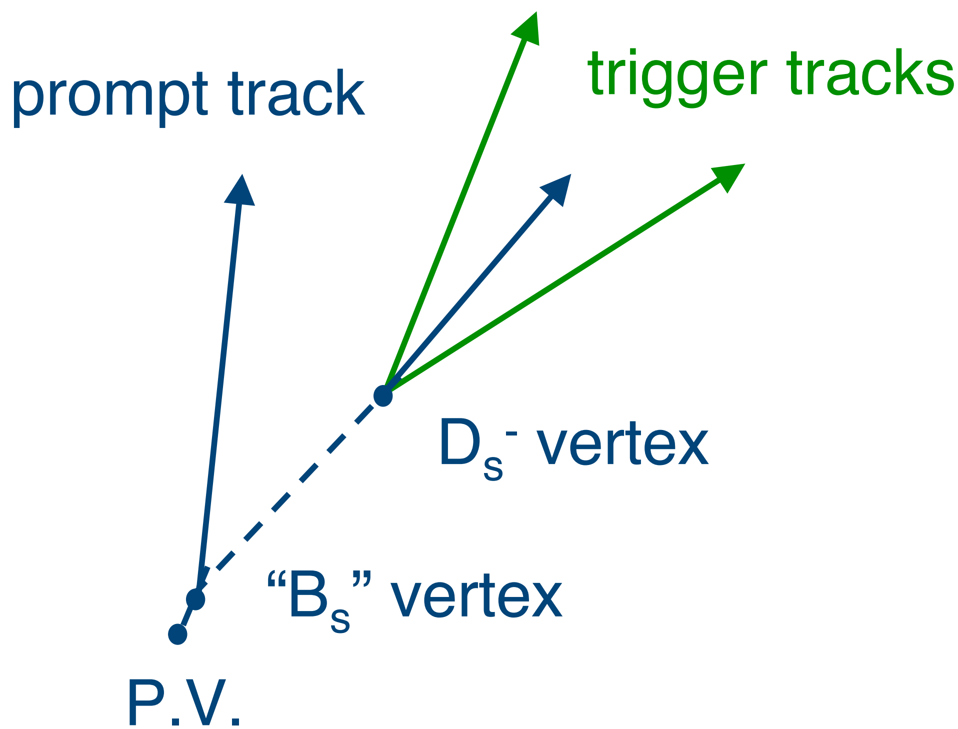
Reminder, measurement significance:

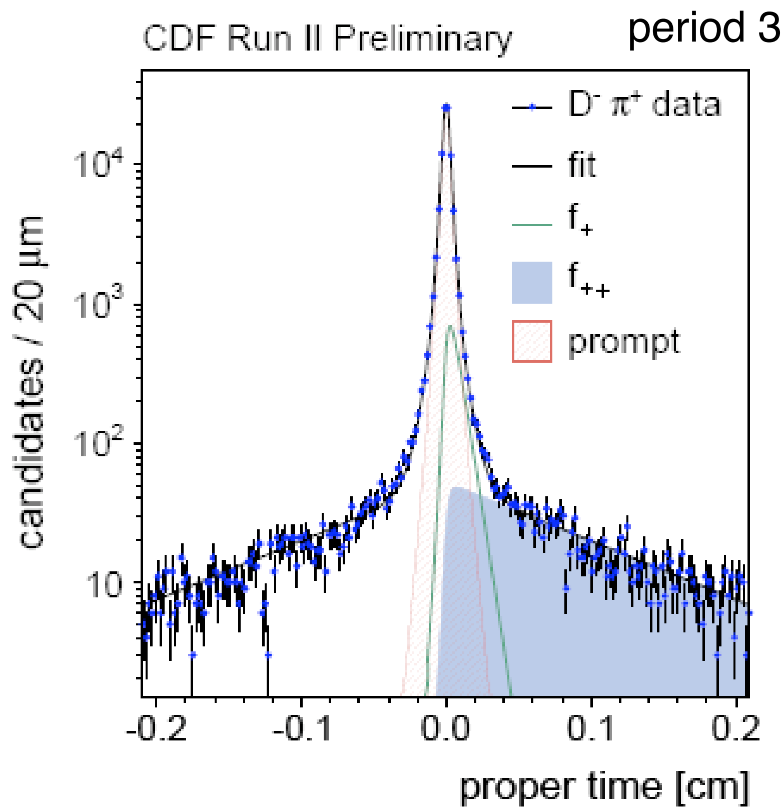
$$\frac{1}{\sigma} = \sqrt{\frac{S\epsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

- significant effect
- fitter has to correctly account for it
- lifetime measurements not very sensitive to resolution
- a dedicated calibration is needed!



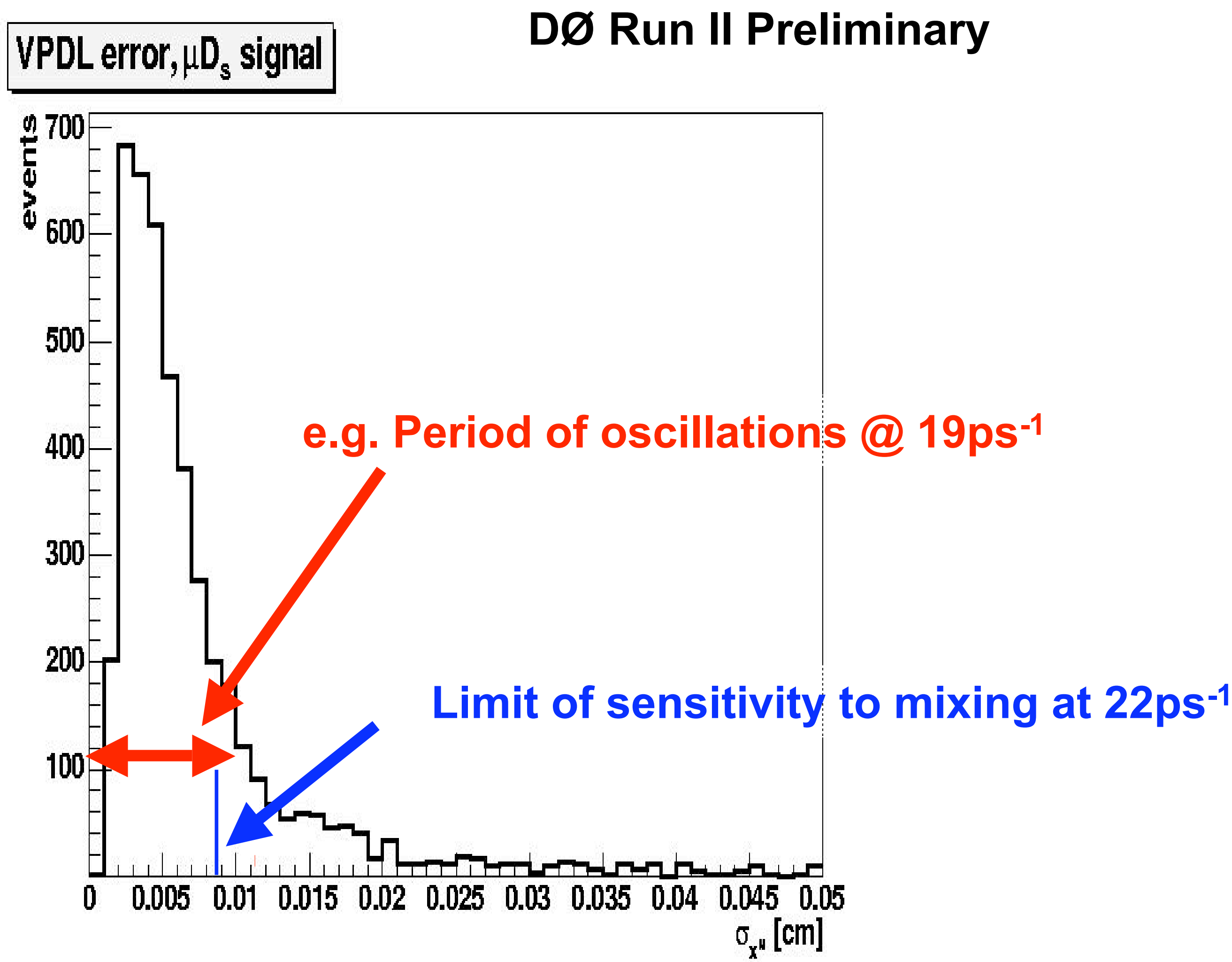
Calibrating the Proper Time Resolution (CDF)





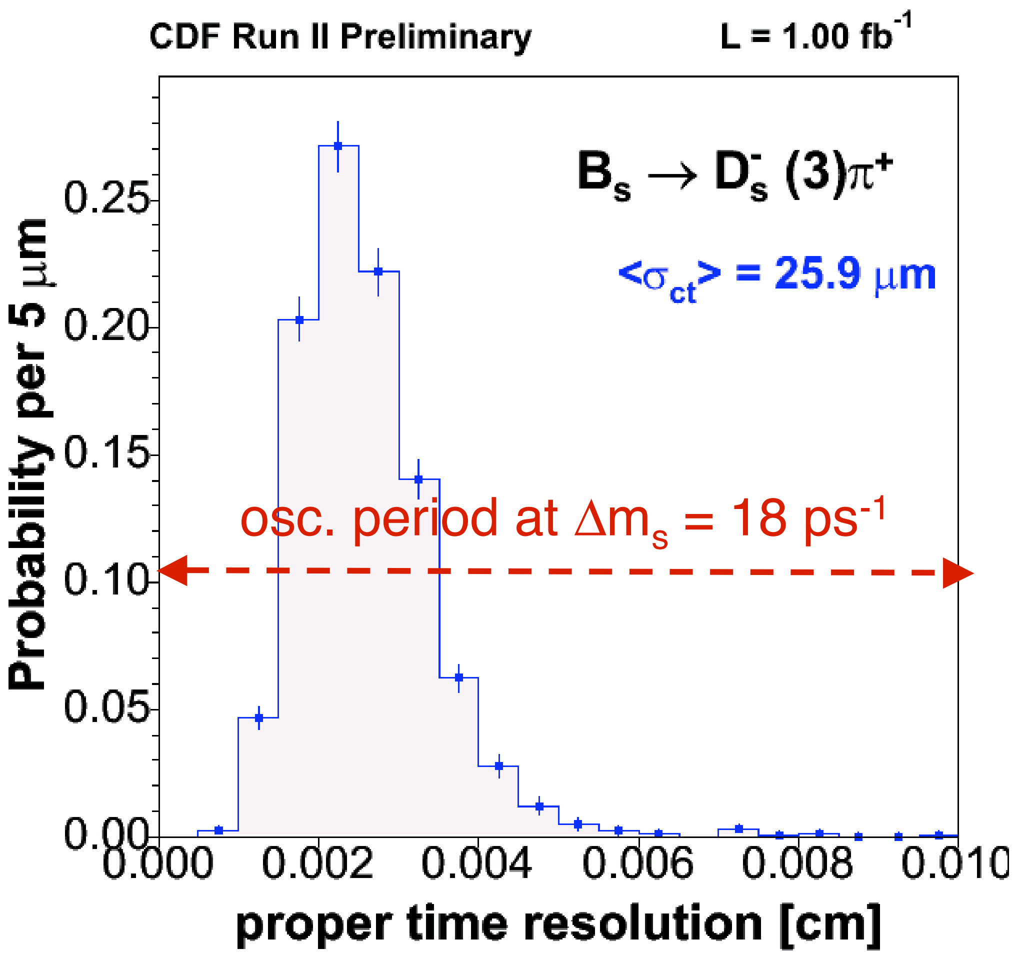
- utilize large prompt charm cross section
- construct "B^0-like" topologies of prompt D^- + prompt track
- calibrate ct resolution by fitting for "lifetime" of "B^0-like" objects

Semileptonic Vertex Resolution (D0)



- Determined by vertex fitting procedure

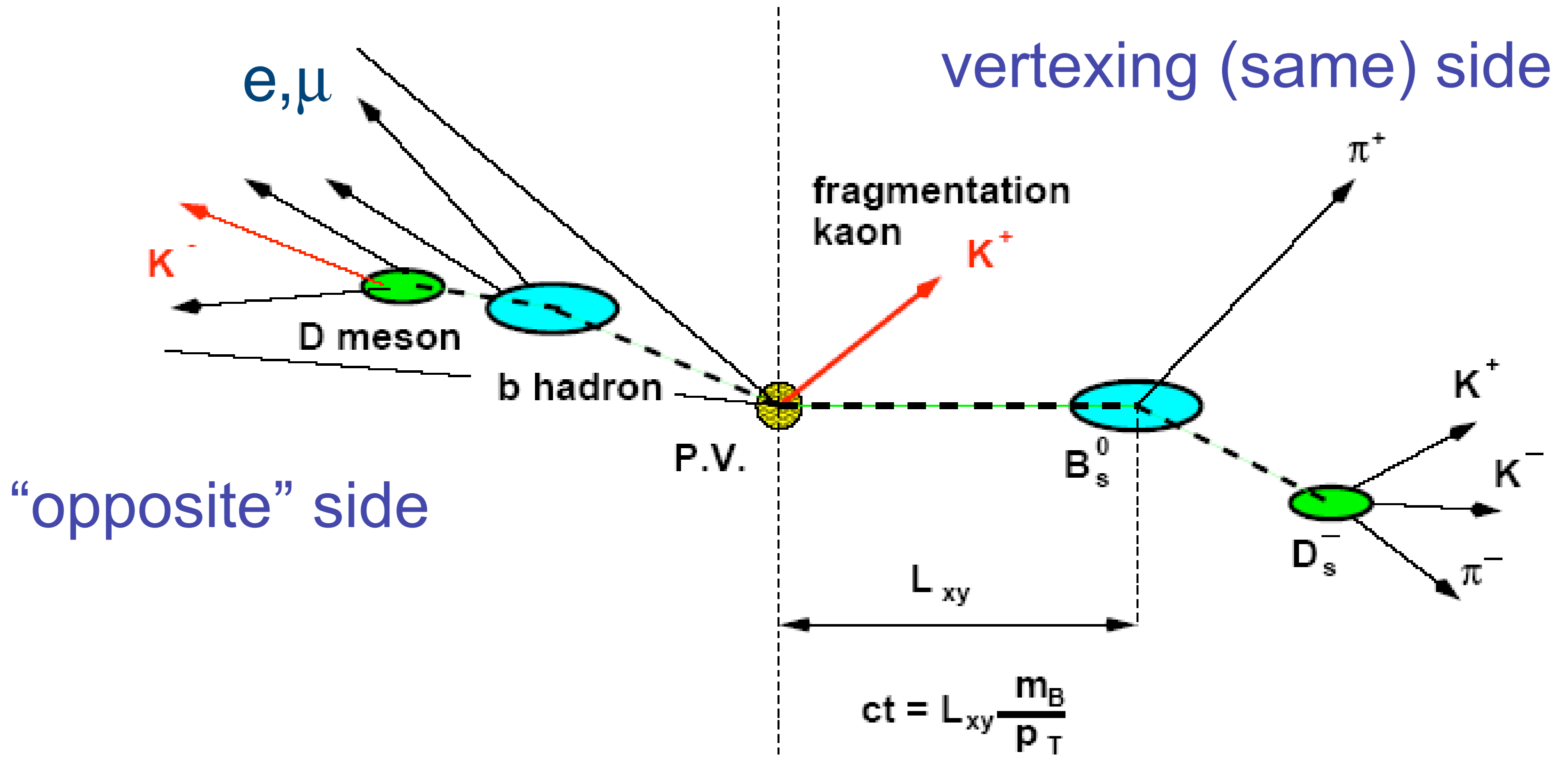
Hadronic B_s Proper Time Resolution



- event by event determination of primary vertex position used
- average uncertainty ~ 26 μm
- this information is used per candidate in the likelihood fit

Flavor Tagging

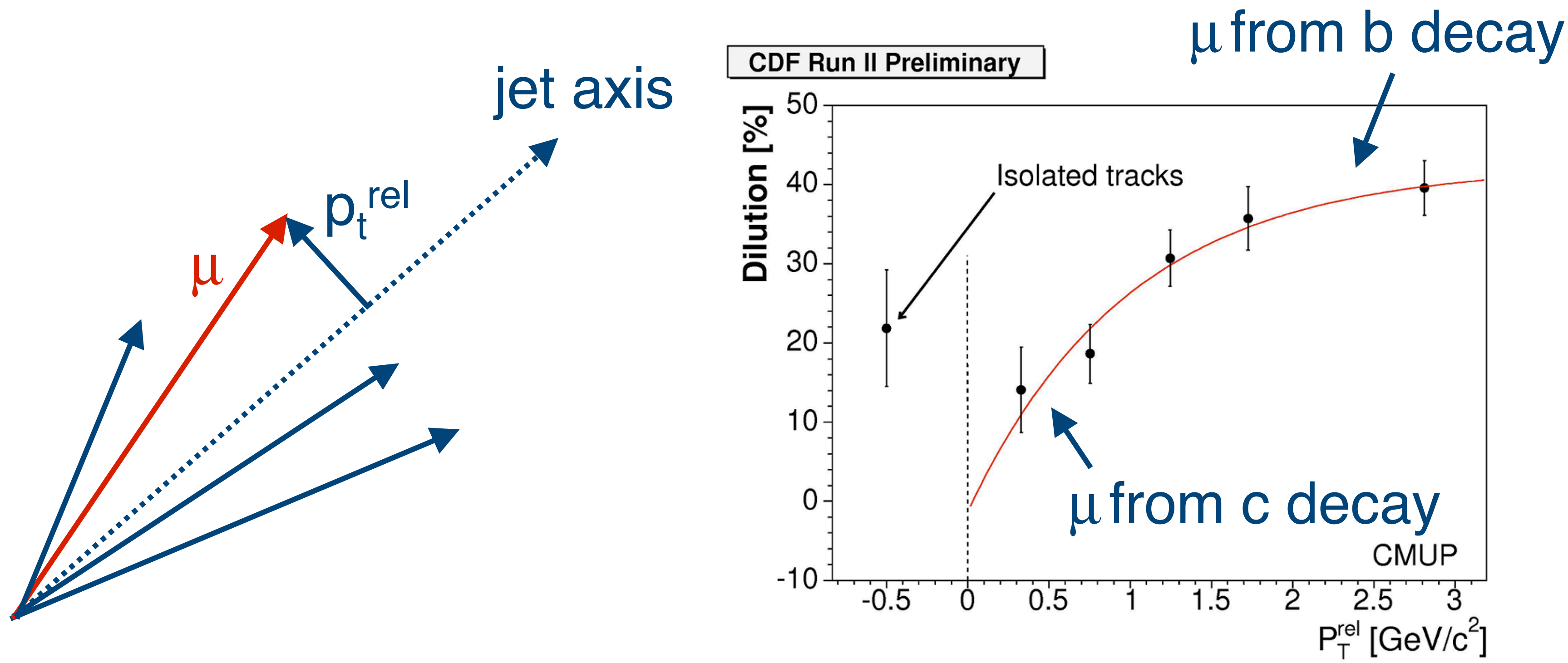
Tagging the B Production Flavor



- Same-side and opposite-side tags are possible !
- use muon, electron tagging, jet charge on opposite side
- jet selection algorithms: vertex, jet probability and highest p_T
- particle ID based kaon tag on same side

Parametrizing Tagger Decisions

- use characteristics of tags themselves to increase their tagging power, example: muon tags



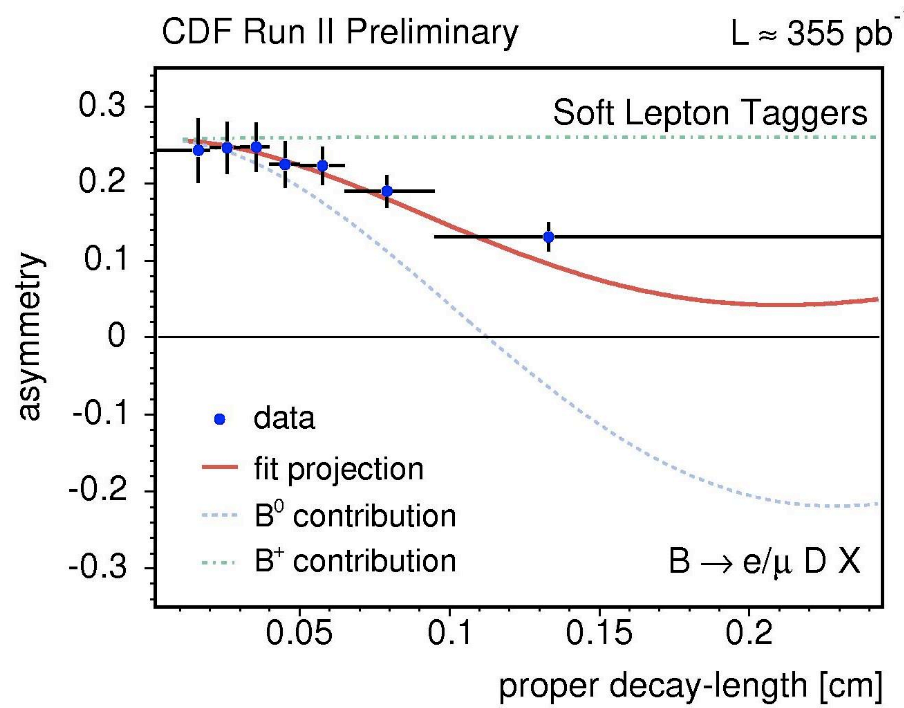
- tune taggers and parametrize event specific dilution
- technique in data works with opposite side tags

Unbinned Likelihood Δm_d Fits

- fit separately in hadronic and semileptonic sample
- per sample, simultaneously measure
  - tagger performance
  - Δm_d
- projection incorporates several classes of tags:

Total OS: $\epsilon D^2 \sim 1.5\%$

semileptonic, ID^-, muon tag



hadronic: $\Delta m_d = 0.536 \pm 0.028\ (stat) \pm 0.006\ (syst)\ ps^{-1}$

semileptonic: $\Delta m_d = 0.509 \pm 0.010\ (stat) \pm 0.016\ (syst)\ ps^{-1}$

world average: $\Delta m_d = 0.507 \pm 0.005\ ps^{-1}$

Flavor tag at D0

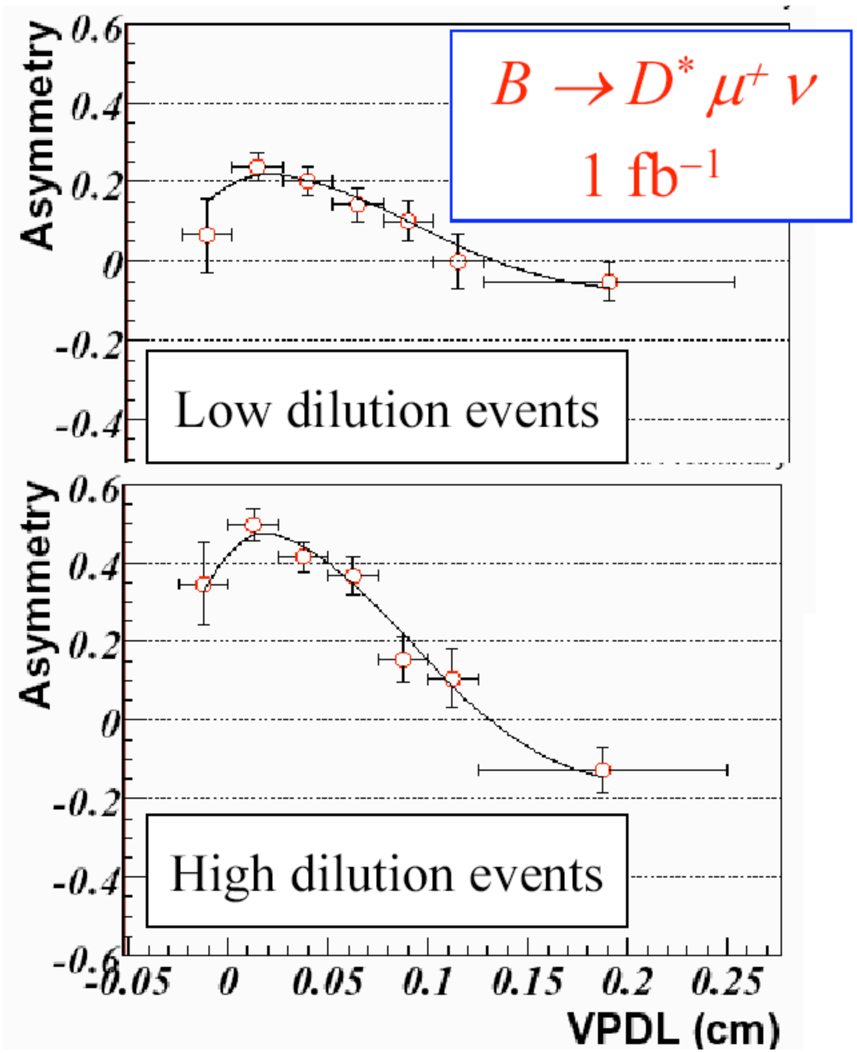
Inputs:

- Jet charge centered on lepton (e or μ)
- Secondary vertex charge
- Recoil charge

Tuned using B_d mixing

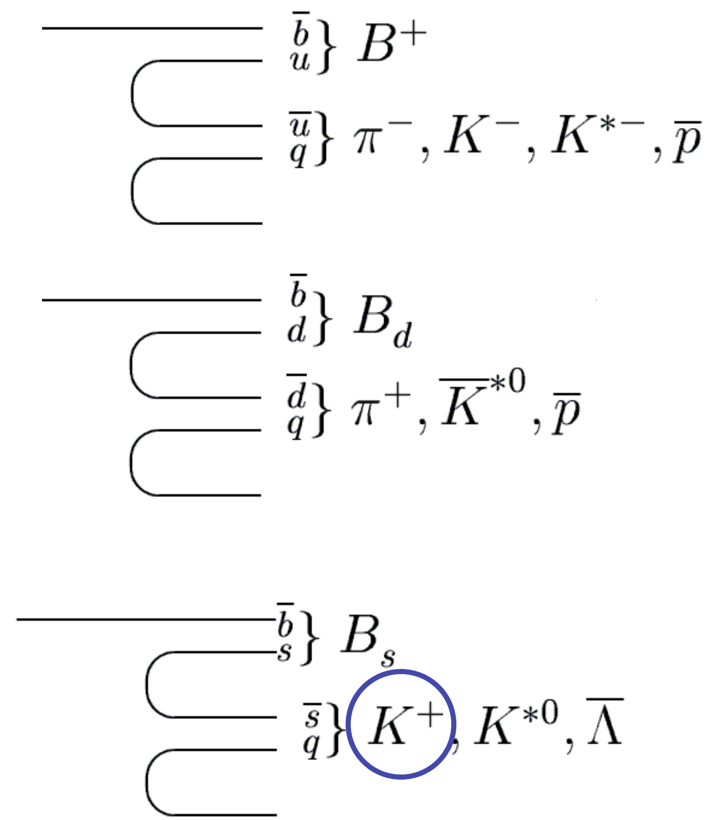
Combined opposite side tag:

$$\varepsilon D^2 = (2.48 \pm 0.21\,^{+0.08}_{-0.06})\%$$

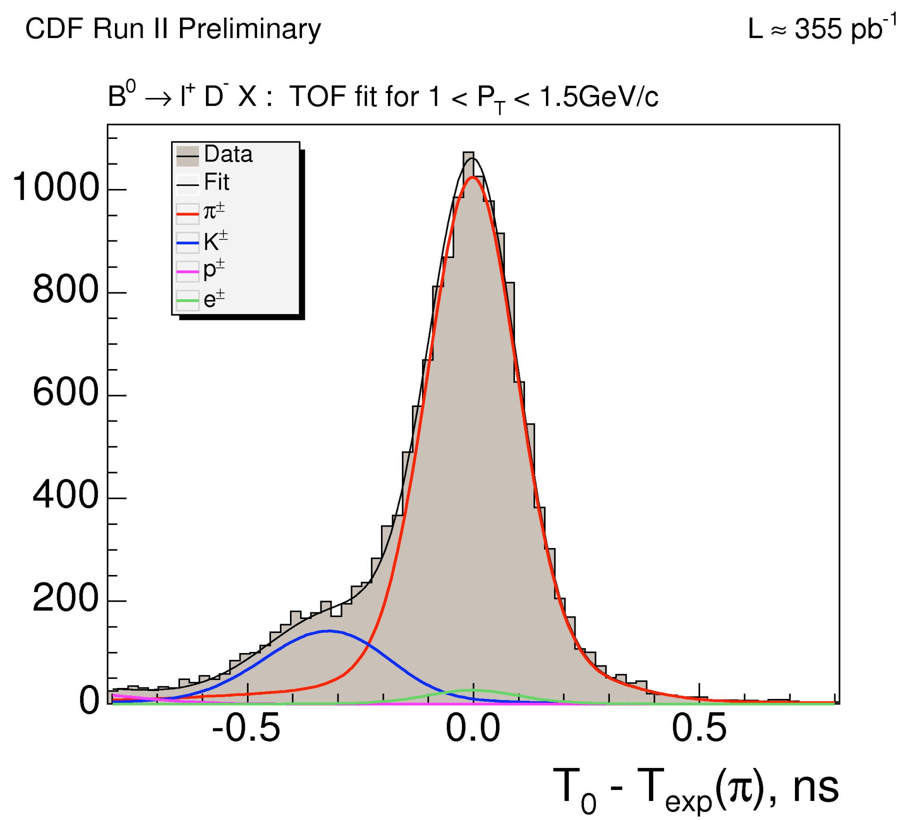


Same Side Kaon Tags

- Exploit b quark fragmentation signatures in event
- B^0/B^+ likely to have a π^-/π nearby
- B_s^0 likely to have a K^+
- use TOF and COT dE/dX info. to separate pions from kaons
- problem: calibration using only B^0 mixing will not work
- tune Monte Carlo simulation to reproduce B^0, B^- distributions, then apply directly to B_s^0

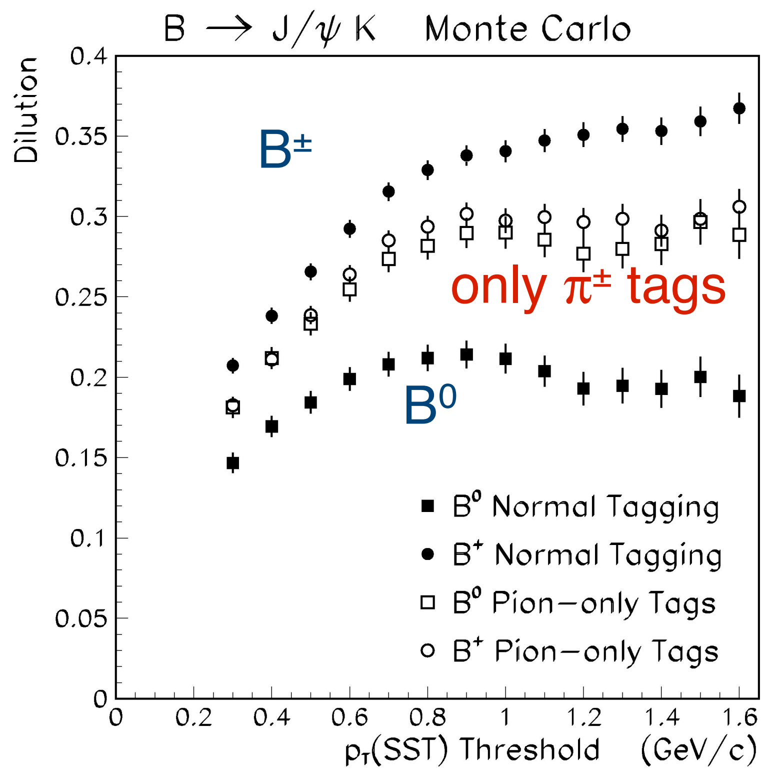


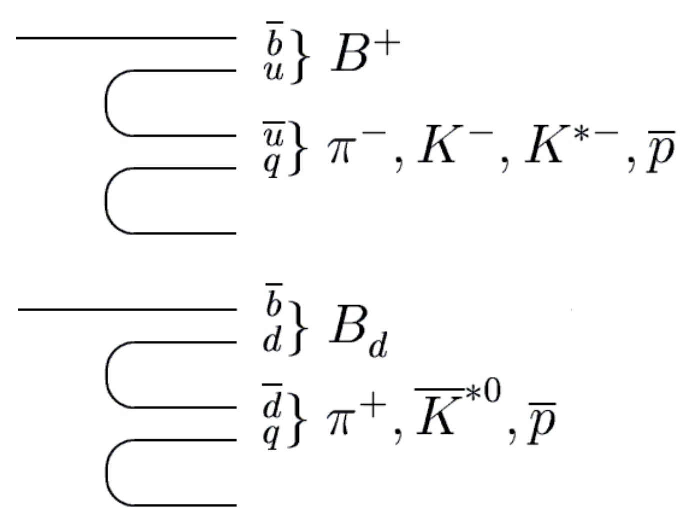
PID from Time Of Flight System



- timing resolution ~100 ps ! resolves kaons from pions up to p ~ 1.5 GeV/c
- TOF provides most of the Particle ID power for SSKT

Kaons Matter in Light B's!

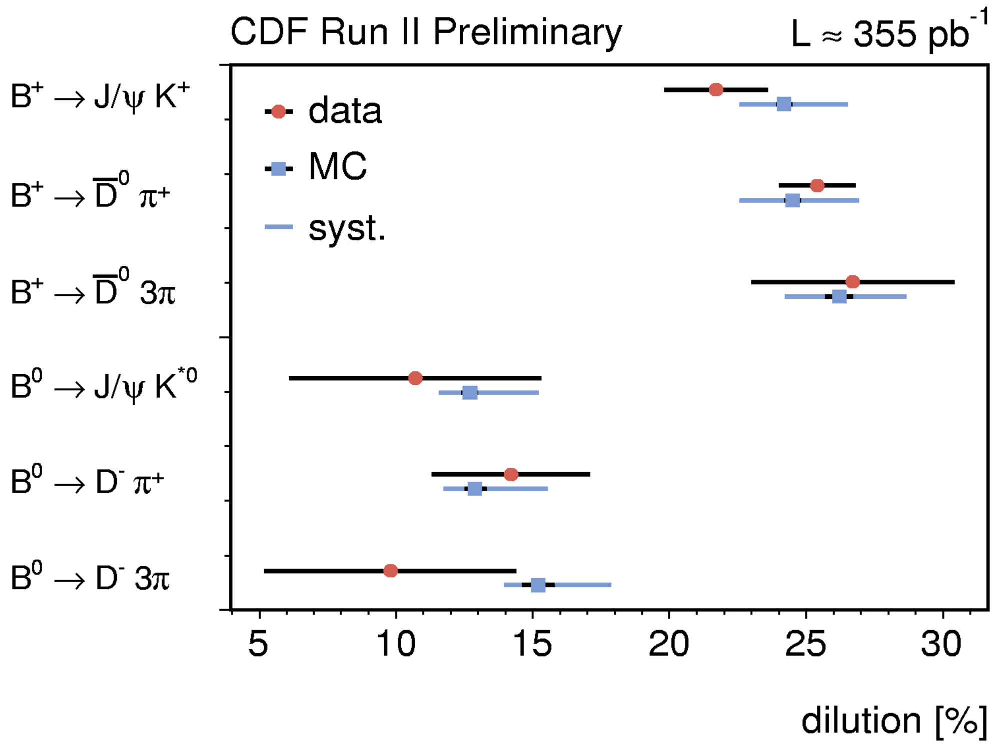




- kaons participate differently in tagging B±, B0
- Monte Carlo simulation has to have correct kinematics AND particle content to get the dilution right!

Calibrating SSKT

- Analogous to transfer scale factor in Opposite Side Tags
- Check dilution in light B meson decays



Data/MC agreement is the largest systematic uncertainty ! O(14%)

Tagger Performance

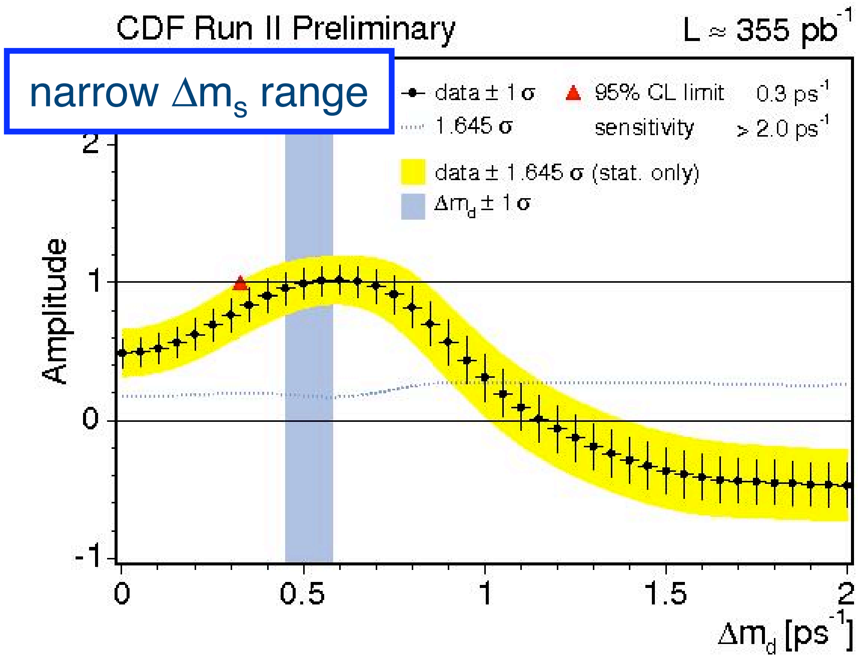
	εD^2 Hadronic (%)	εD^2 Semileptonic (%)
Muon	0.48 ± 0.06 (stat)	0.62 ± 0.03 (stat)
Electron	0.09 ± 0.03 (stat)	0.10 ± 0.01 (stat)
JQ/Vertex	0.30 ± 0.04 (stat)	0.27 ± 0.02 (stat)
JQ/Prob.	0.46 ± 0.05 (stat)	0.34 ± 0.02 (stat)
JQ/High p_T	0.14 ± 0.03 (stat)	0.11 ± 0.01 (stat)
Total OST	1.47 ± 0.10 (stat)	1.44 ± 0.04 (stat)
SSKT	3.42 ± 0.98 (syst)	4.00 ± 1.02 (syst)

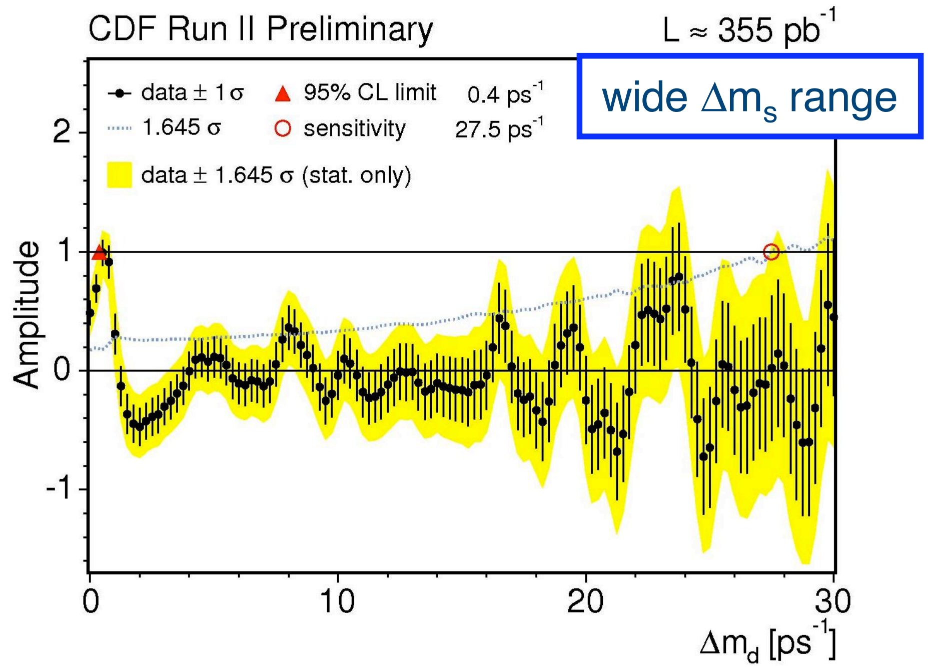
- use exclusive combination of tags on opposite side
- same side – opposite side combination assumes independent tagging information

The Procedure

Amplitude Scans

- Example: B^0 Mixing signal in CDF hadronic decays
- Points: $A \pm \sigma(A)$ from likelihood fit vs Δm. Yellow: $A \pm 1.645\ \sigma(A)$
- Δm values where $A + 1.645\ \sigma(A) < 1$ are excluded at 95% C.L.
- Sensitivity estimate from $1.645\ \sigma(A) = 1$



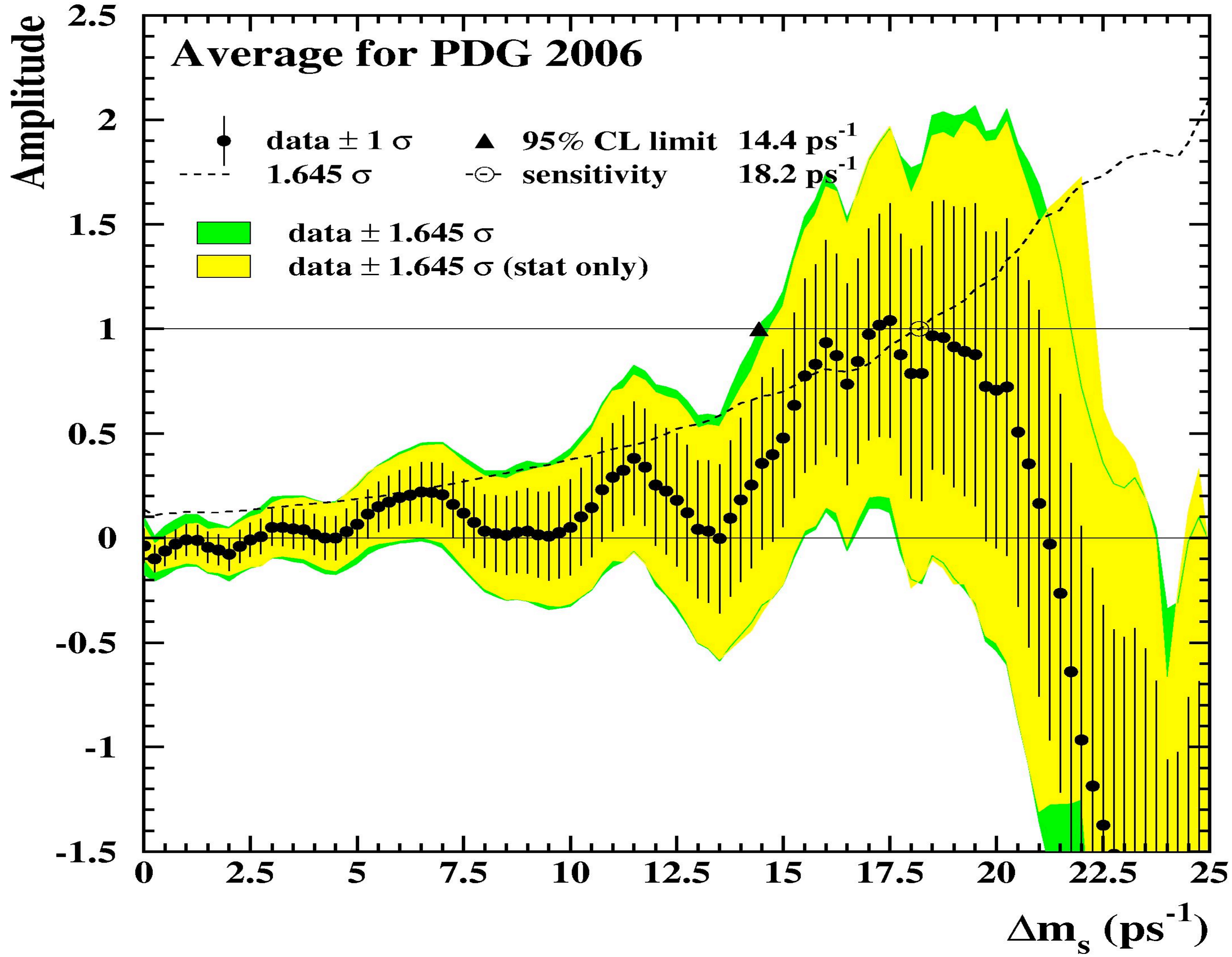


☞ Amplitude most suitable for setting limits from combined experiments.

☞ Evaluating the significance of an oscillation signal requires accounting for multiple tested points.

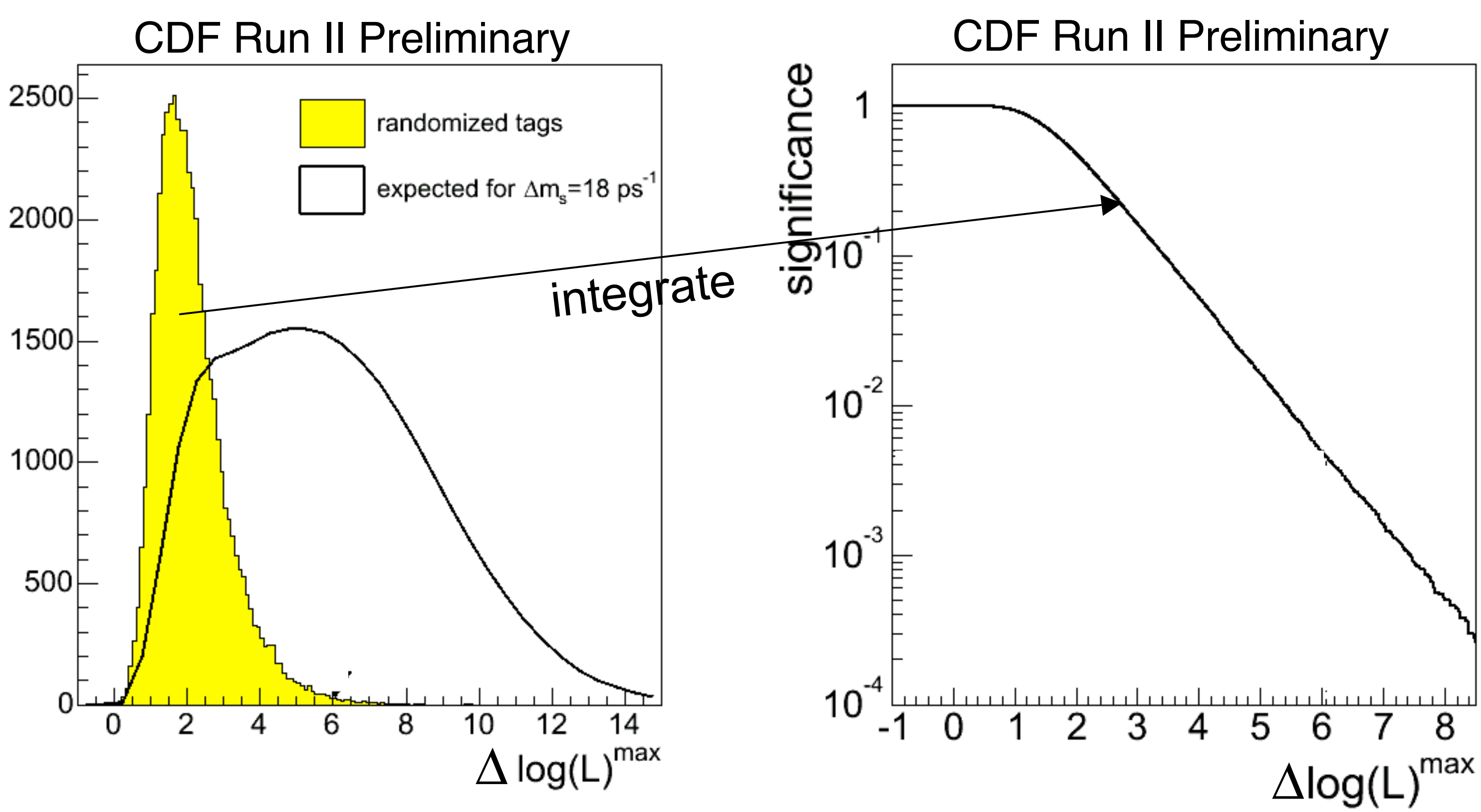
☞ Both CDF and D0 adopted a method based on Likelihood-Ratio

World Knowledge on Δm_s



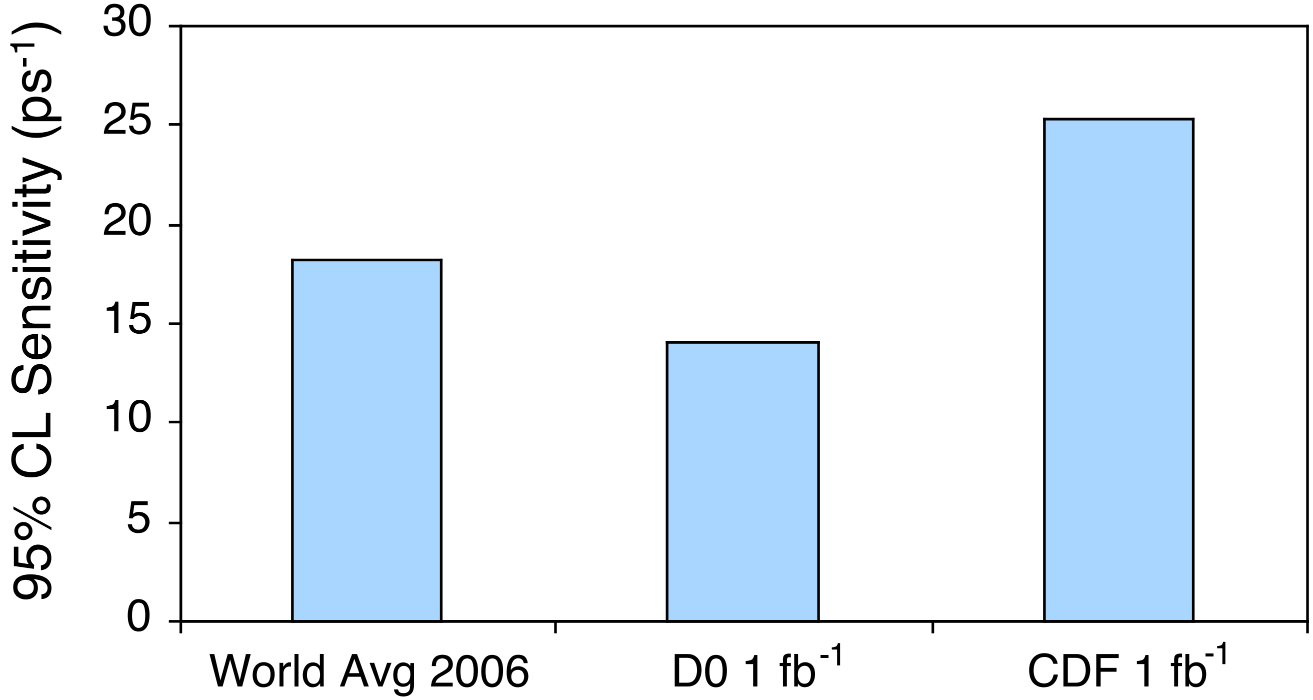
Testing for oscillations

- Compare oscillation hypothesis at Δm_s with "random tags" hypothesis (H_0)
  - N.B. "no signal" ≠ "no mixing" - that hypothesis is definitely excluded
- Use maximum value of $\Delta\log(L) = \log[\ L(x_s)\ /\ L(\infty)\ ]$ as test variable (LR).
  - Height of highest likelihood peak. *More powerful discriminant than A/σ(A)*
- Probability of random tag fluctuations easily evaluated on data (randomized tags) or toy Monte Carlo



The Data

Measurement Sensitivity



- Estimated from data - can evaluate a-priori
- CDF measurement is more sensitive than the world-average knowledge.

D0 Likelihood Scan

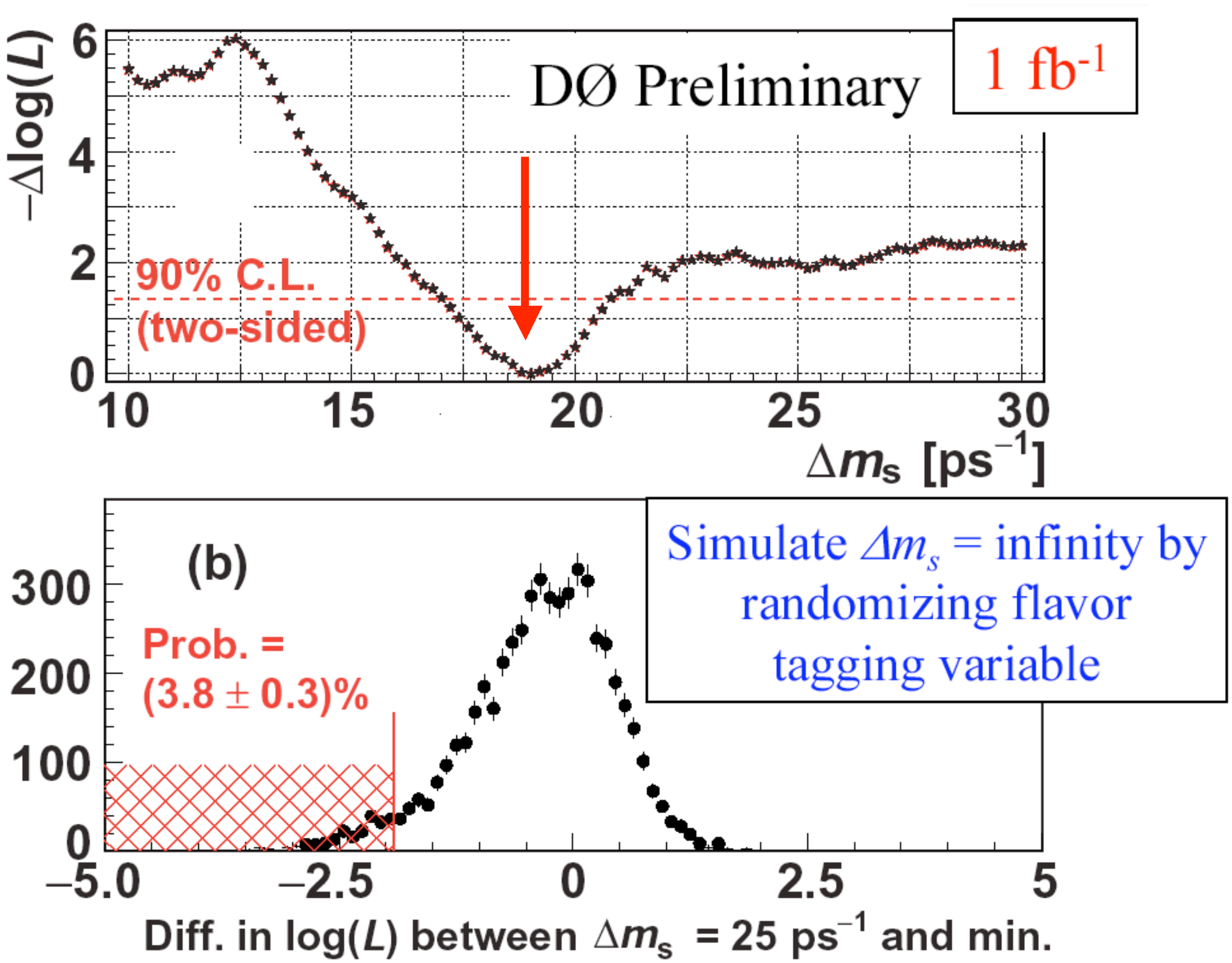
Probability for this measurement to lie in the range

$16 < \Delta m_s < 22 ps^{-1}$

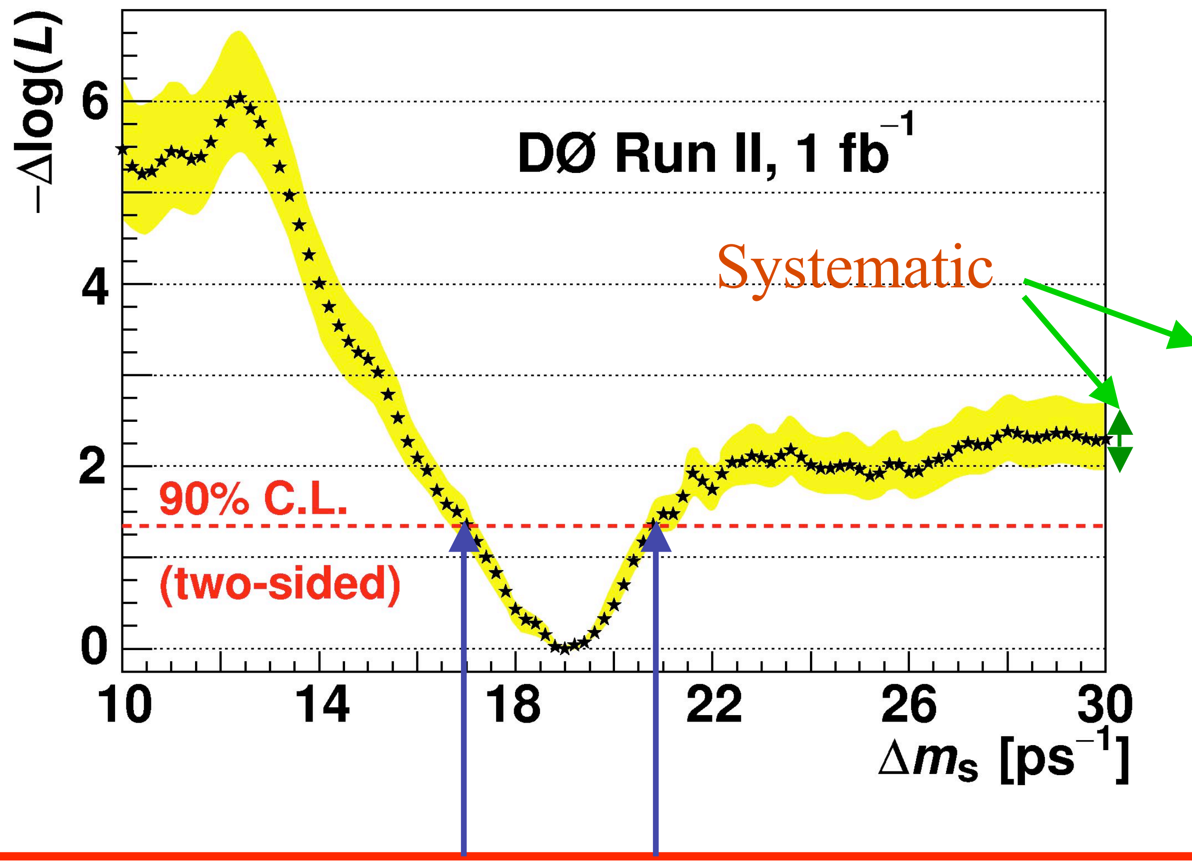
Given a true value:

Δm_s = infinity: 3.8%

$\Delta m_s = 19\ ps^{-1}$: 15%



D0 2-sided Limits from LR



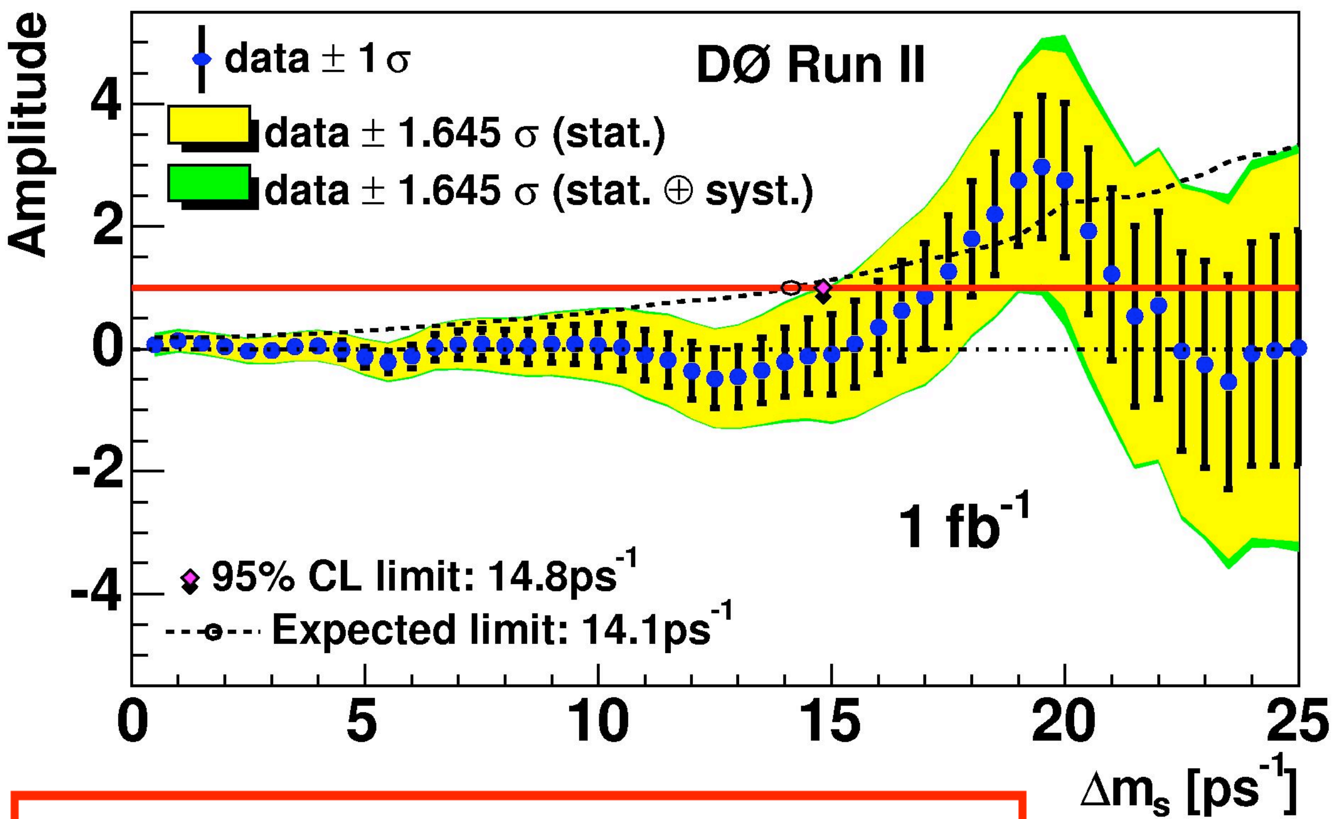
- Resolution
- K-factor variation
- BR ($B_s \to \mu D_s X$)
- VPDL model
- BR ($B_s \to D_s D_s$)

Have no sensitivity above 22 ps^{-1}

17 < Δm$_s$ < 21 ps^{-1} @ 90% CL assuming Gaussian errors

Most probable value of *Δm$_s$* = 19 ps^{-1}

D0 Amplitude Scan

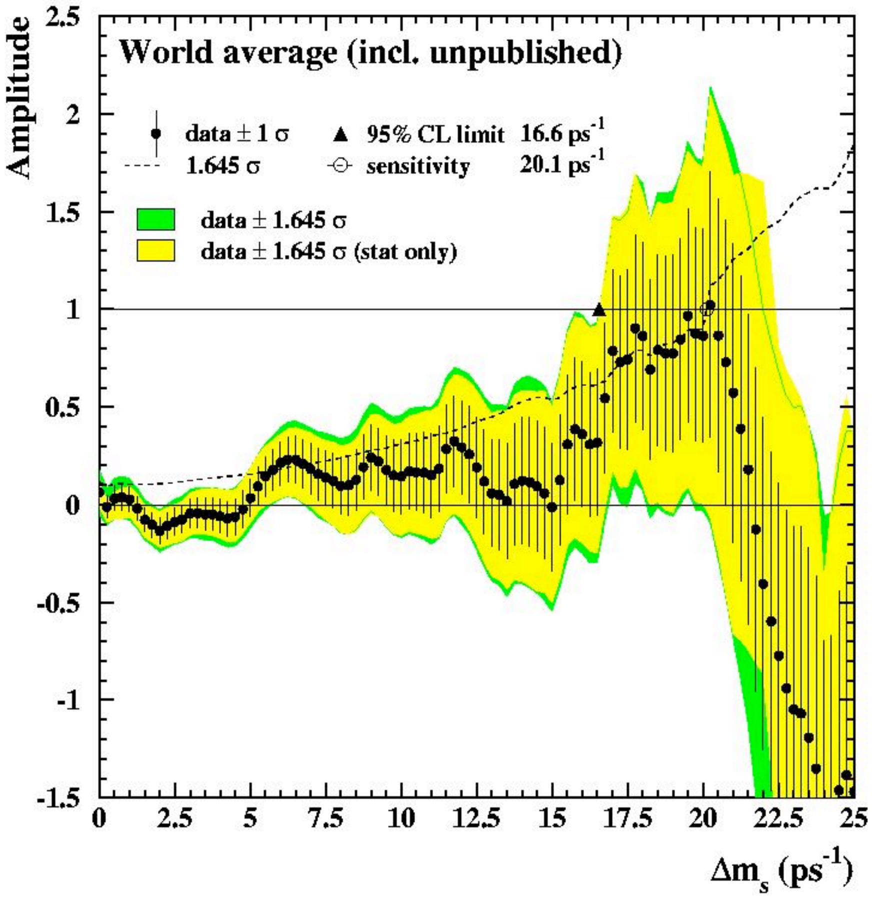


$\Delta m_s > 14.9$ ps^{-1} @ 95% CL

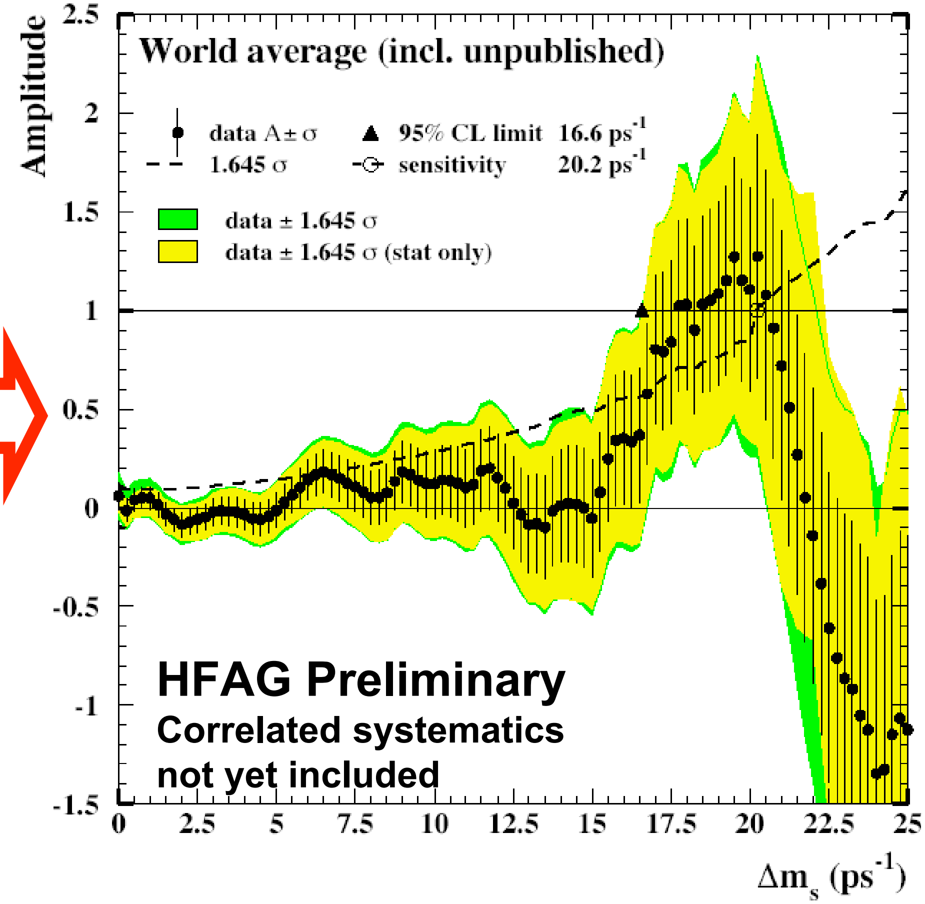
- Deviation of the amplitude at 19 ps-1

  2.5σ from 0 , 1.6σ from 1

D0 + World Average



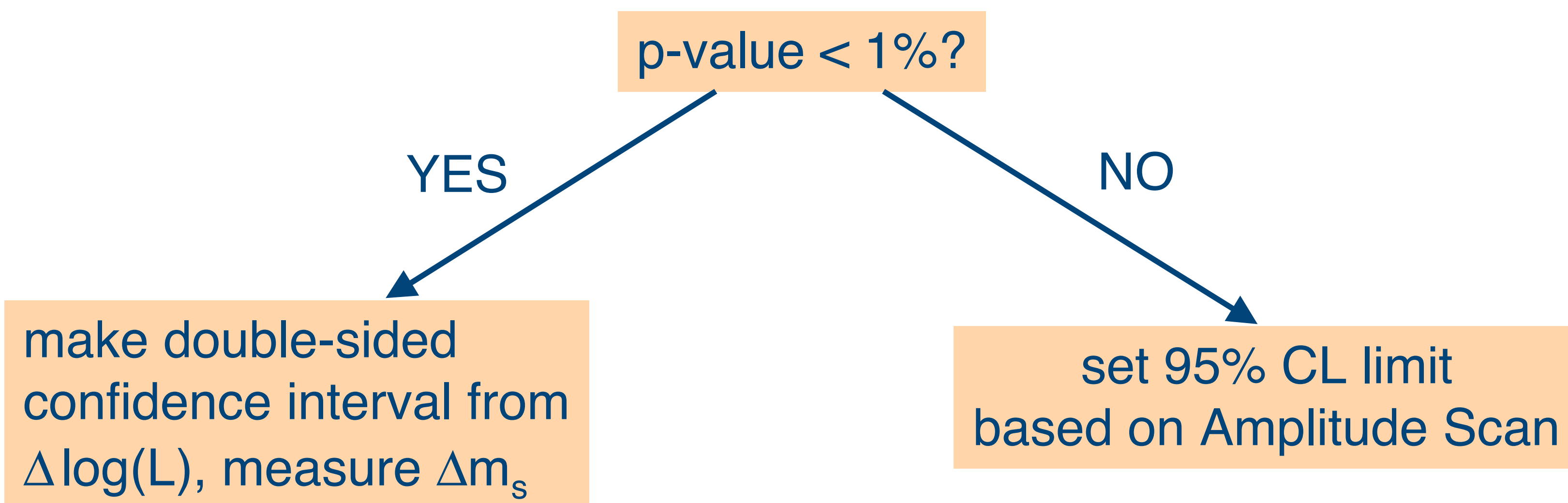
With current D0 result



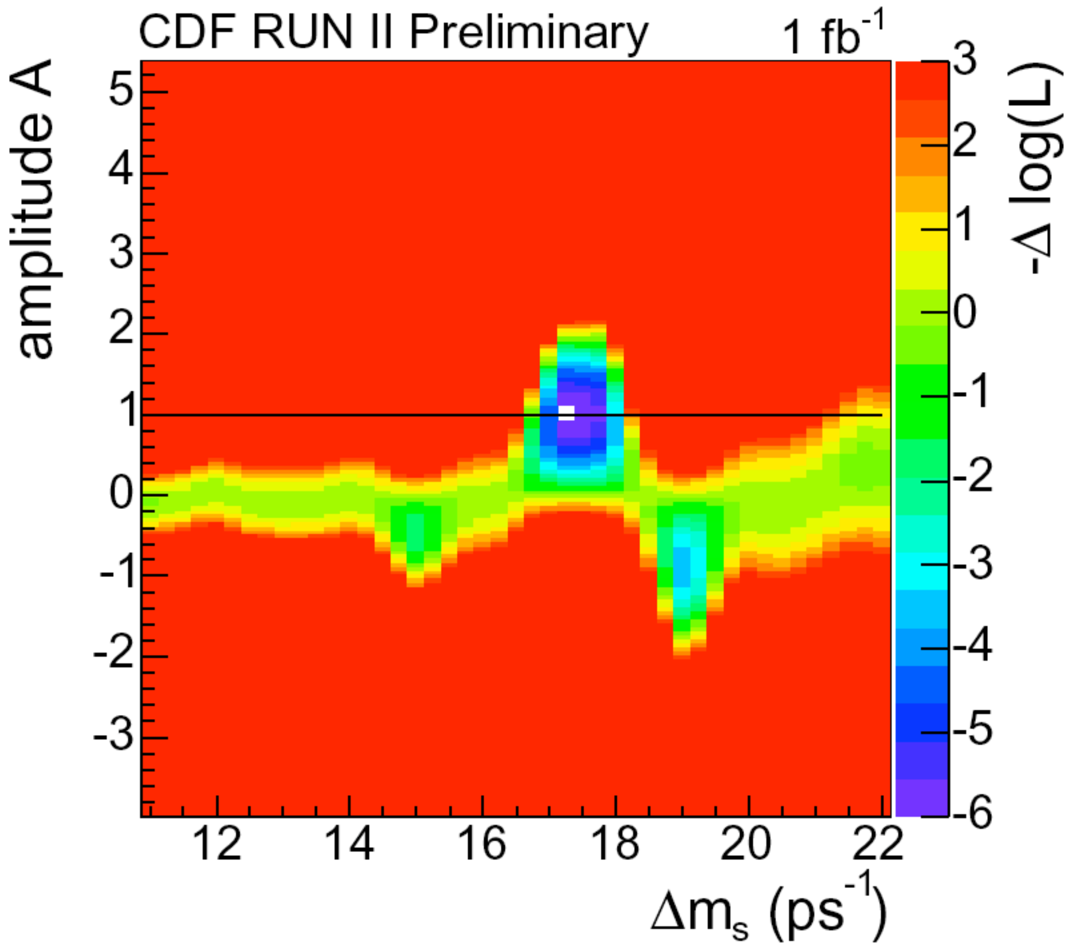
@19ps^{-1}: 1.5σ → 2.3σ

CDF blind Procedure

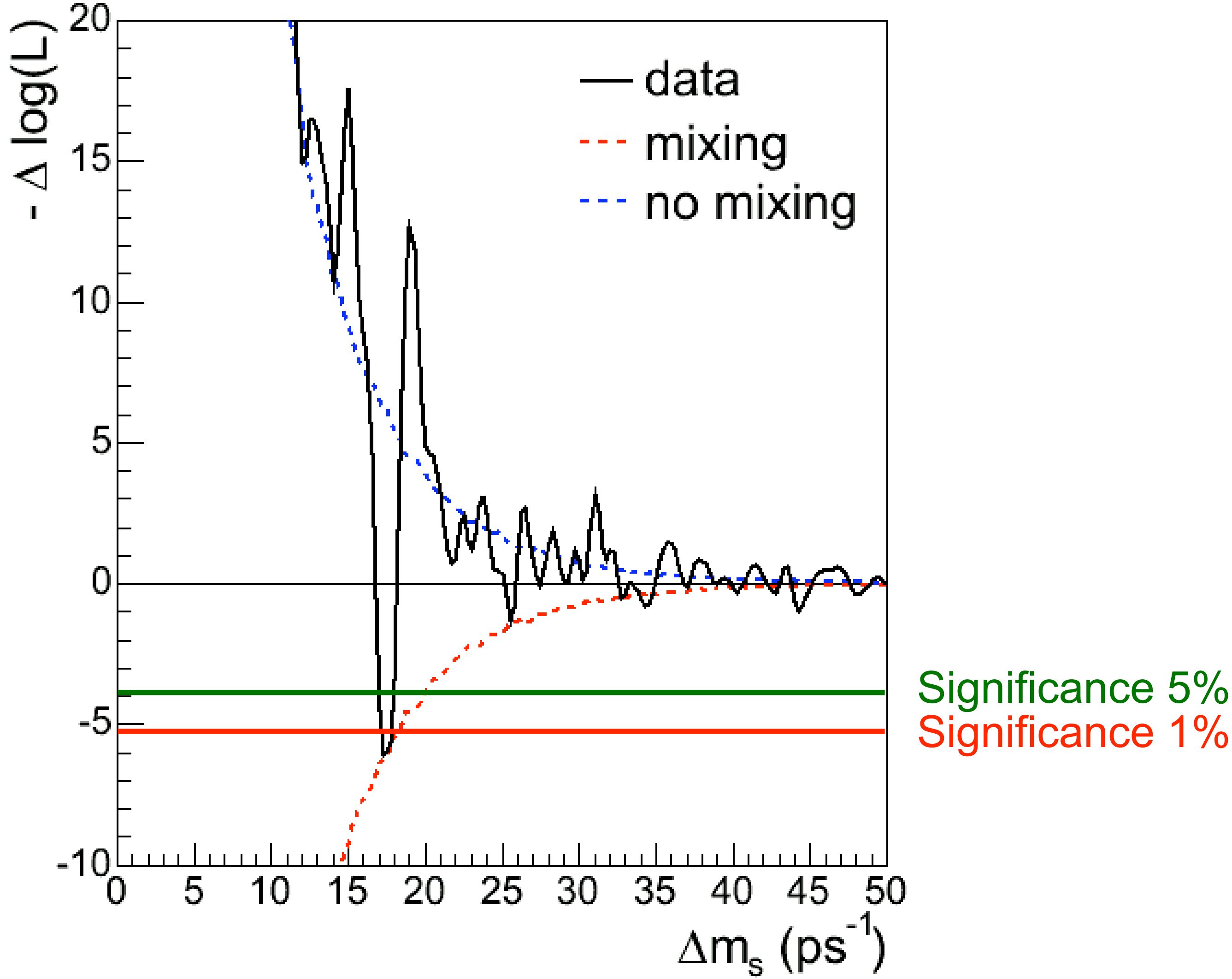
- decided upon before un-blinding the 1 fb^{-1} of data
- p-value: probability that background fluctuation would produce observed effect
- p-value to be estimated using Δ(ln L) method
- no search window to be used



CDF 2-D Likelihood plot

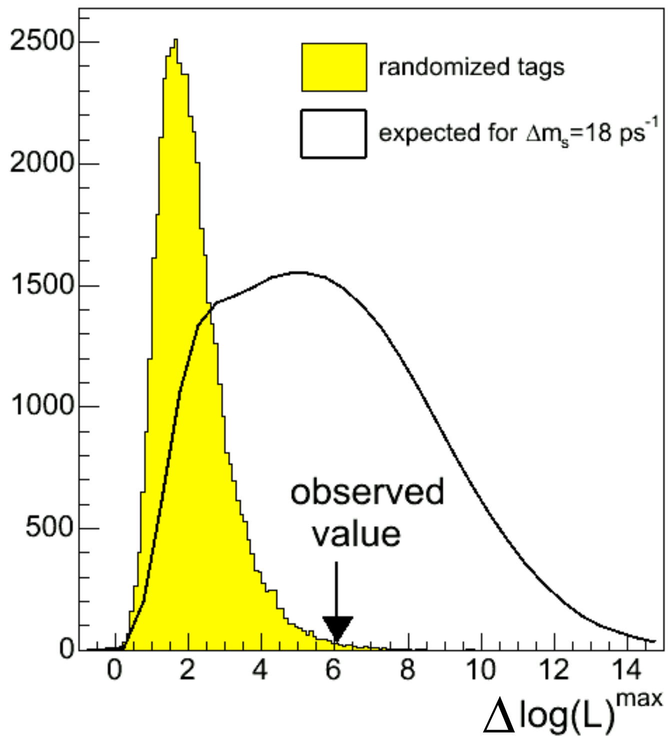


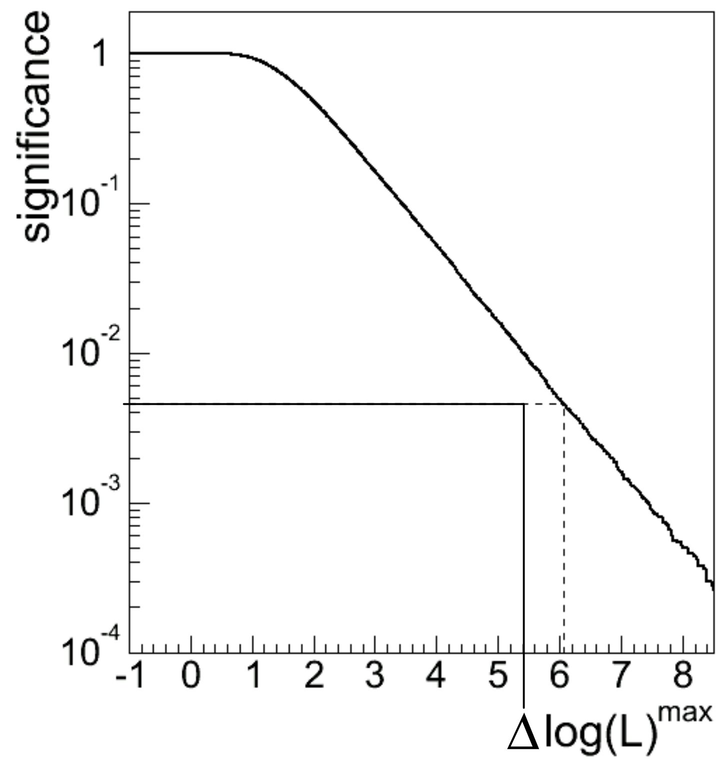
CDF Likelihood Scan



Probability of $\Delta\log(L) > 6.06$ from random tags = 0.5%

Likelihood Significance (CDF)



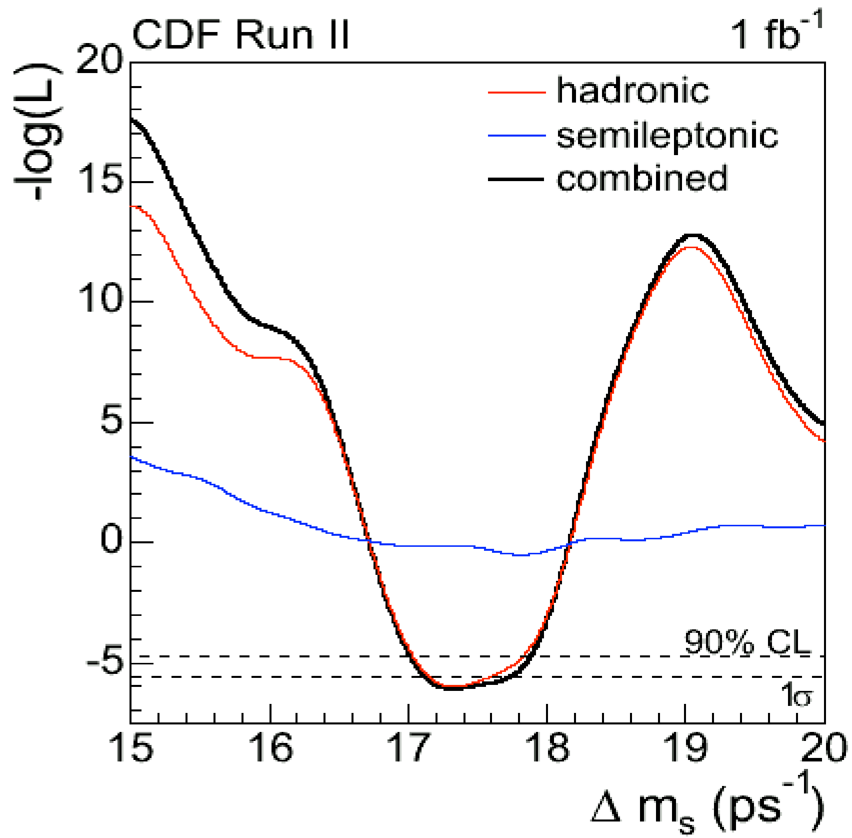


- randomize tags 50 000 times in data, find maximum Δlog(L)

in 228 experiments, Δlog(L) ¸ 6.06

- <u>*No restriction on range:*</u> Δm_s *from 0 to 35*
- probability of fake from random tags = 0.5% ! measure Δm_s!

Measurement of Δm_s



$\Delta m_s = 17.33\ ^{+0.42}_{-0.21}$ (stat) ± 0.07 (syst) ps^{-1}

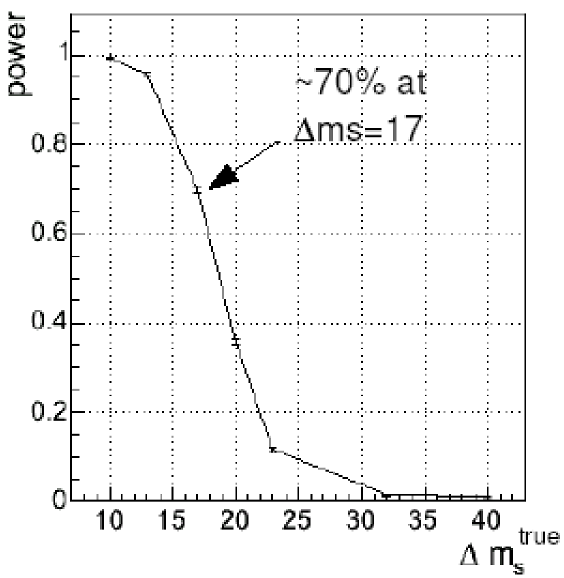
the measurement is already very precise! (at 2.5% level)

Δm_s in [17.00, 17.91] ps^{-1} at 90% CL

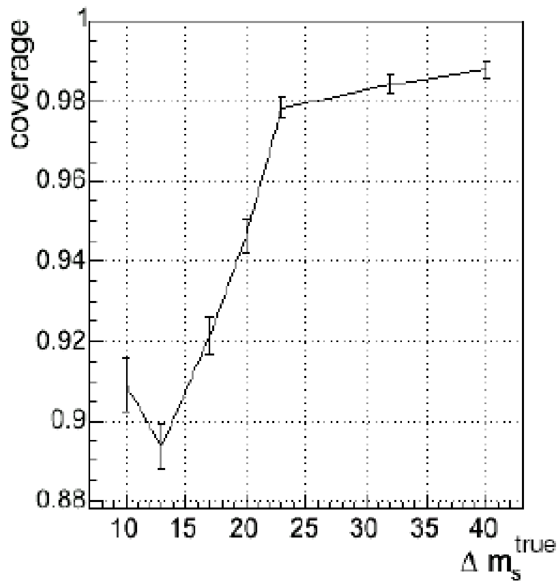
Δm_s in [16.94, 17.97] ps^{-1} at 95% CL

Coverage check

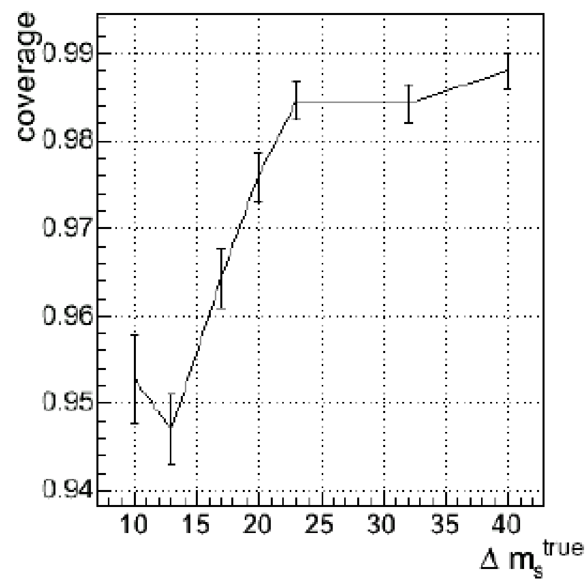
probability of seeing a significance < 1%



coverage 90% CL

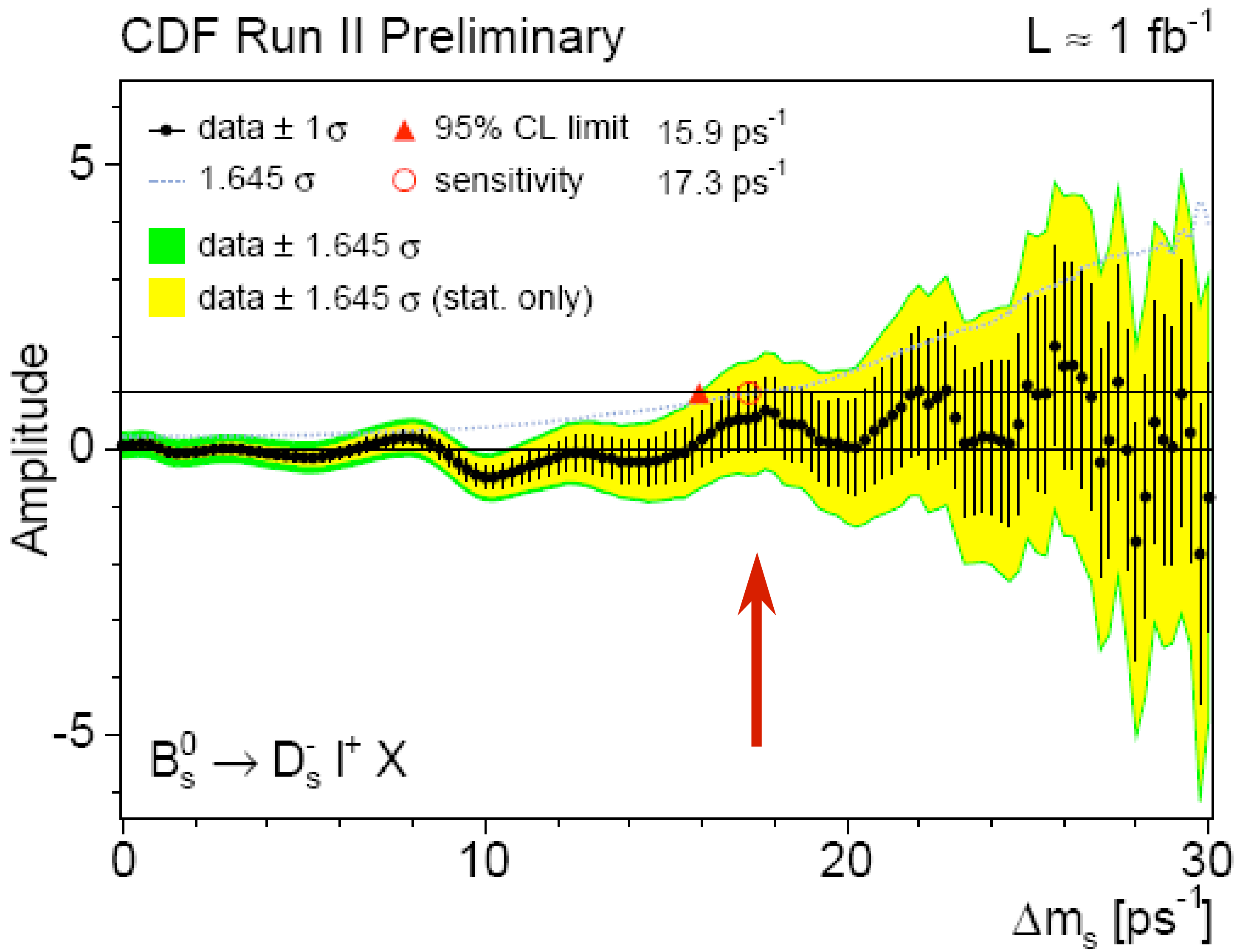


coverage 95% CL

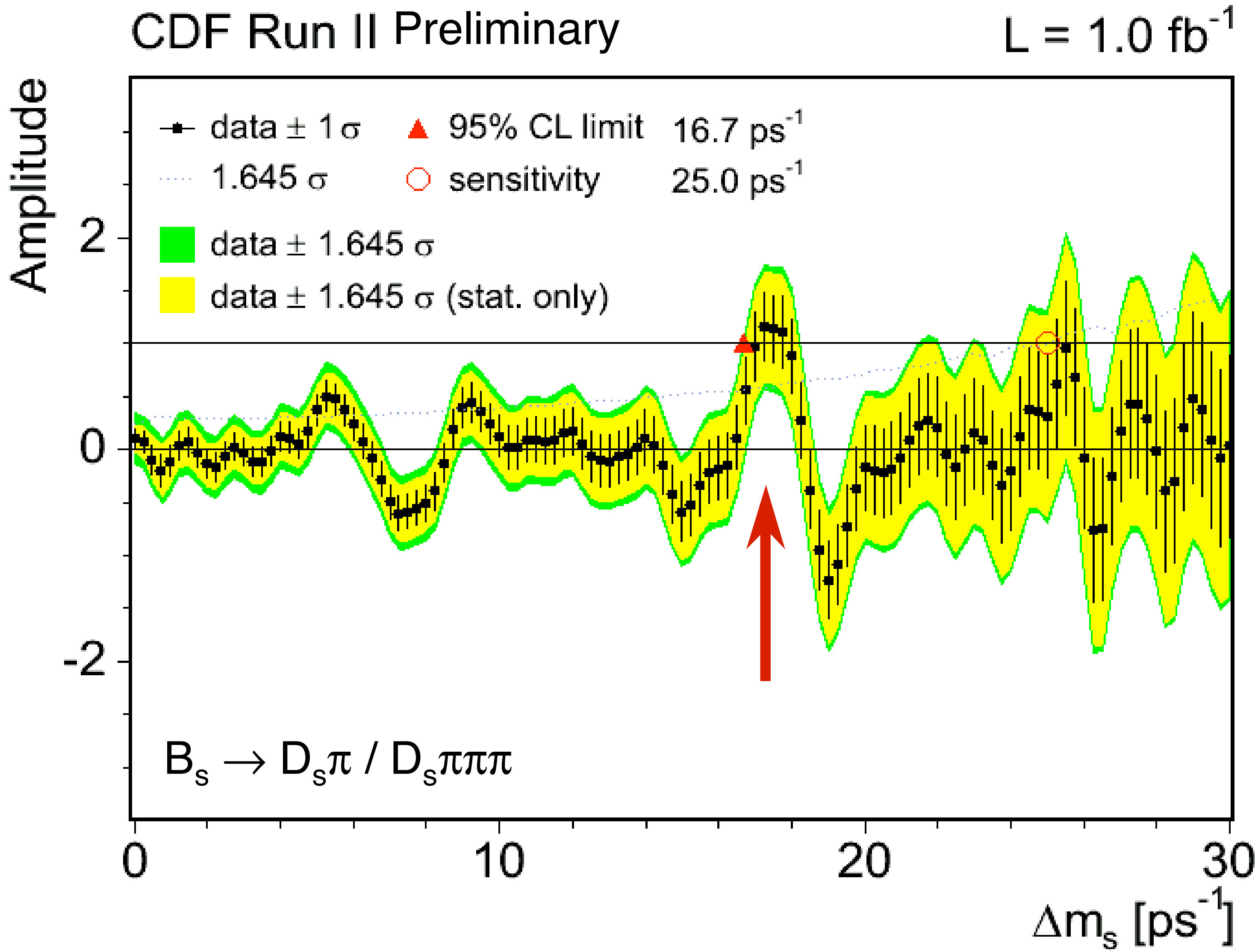


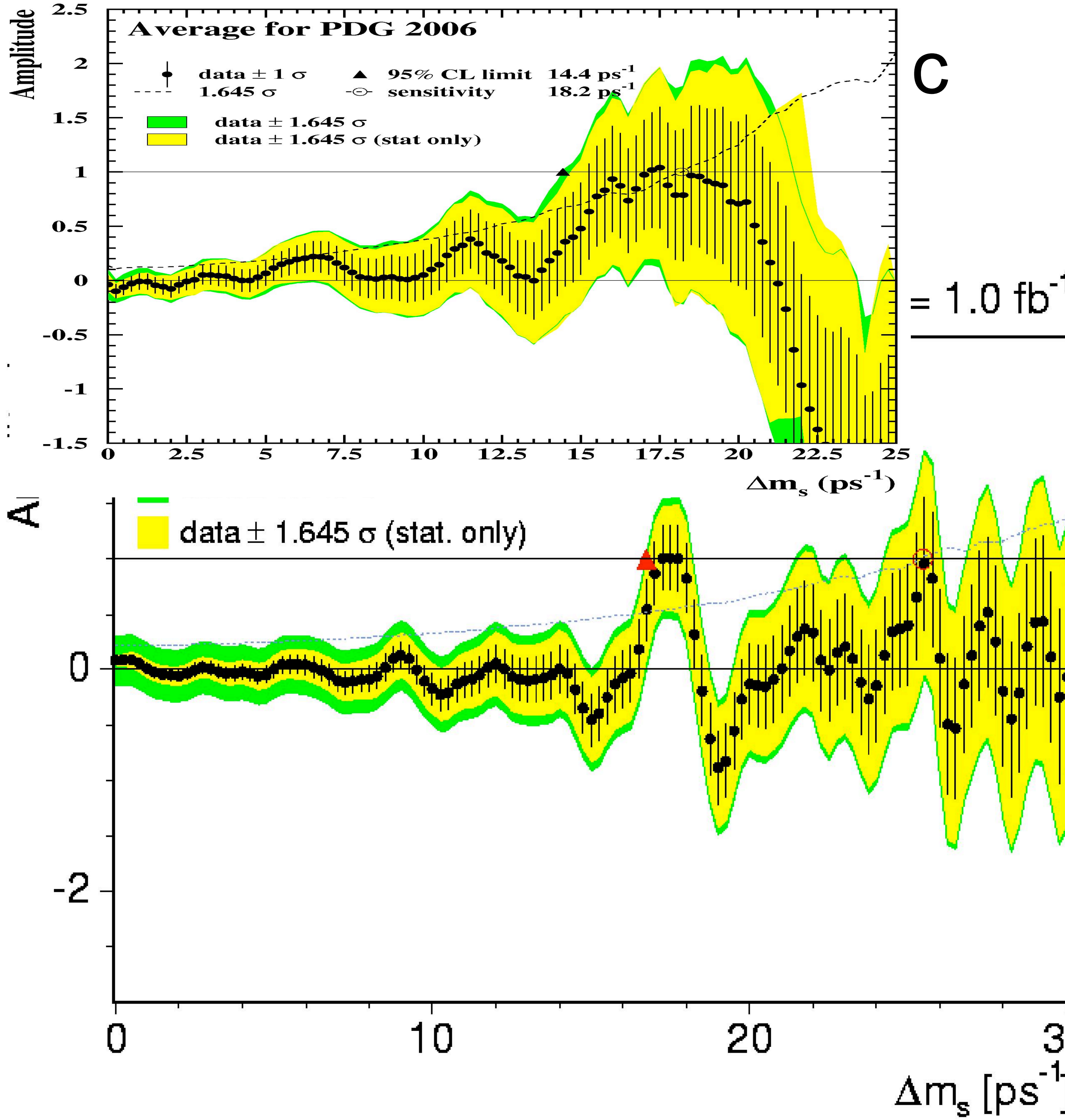
- For large Δm_s: coverage determined by requiring significance of 1%
- For small Δm_s: exactly what we expect
- Around Δm_s = ~ 17 ps^{-1} slightly conservative

CDF Semileptonic Scan



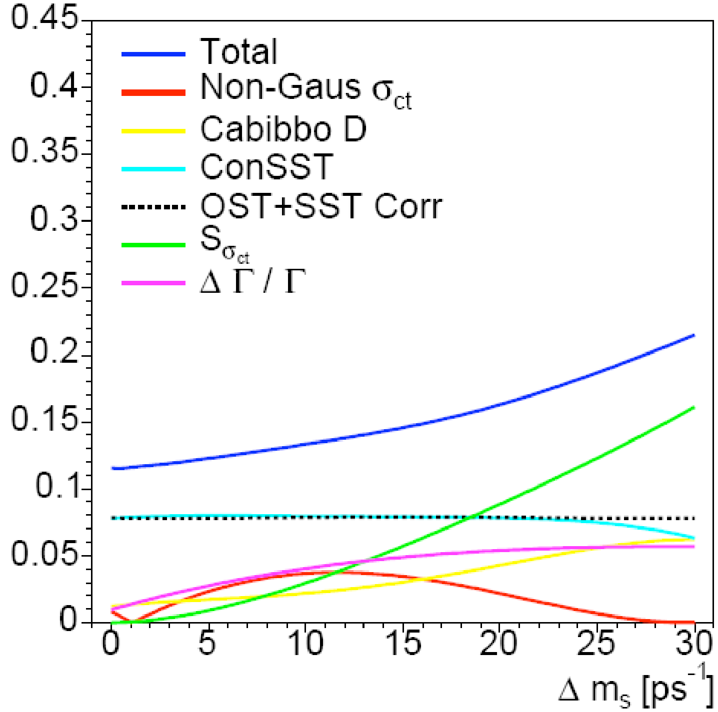
CDF Hadronic Scan



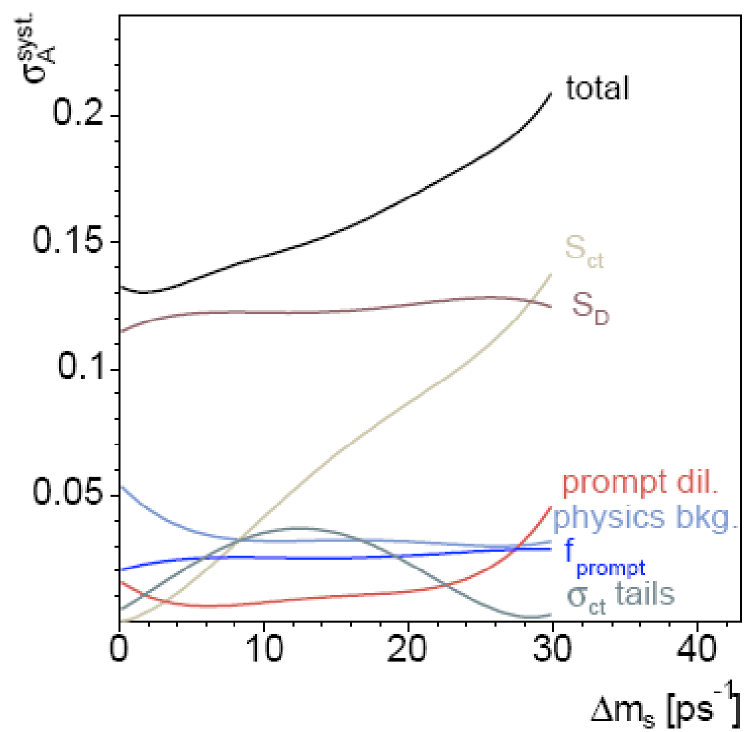

Average for PDG 2006
data ± 1 σ
1.645 σ
95% CL limit 14.4 ps-1
sensitivity 18.2 ps-1
data ± 1.645 σ
data ± 1.645 σ (stat only)
Amplitude
Δms (ps-1)
C
= 1.0 fb-1
data ± 1.645 σ (stat. only)
Δms [ps-1]

Systematic Uncertainties

Hadronic



Semileptonic



- related to absolute value of amplitude, relevant only when setting limits
  - cancel in A/σ_A, folded in in confidence calculation for observation
  - systematic uncertainties are very small compared to statistical

Systematic Uncertainties on Δm_s

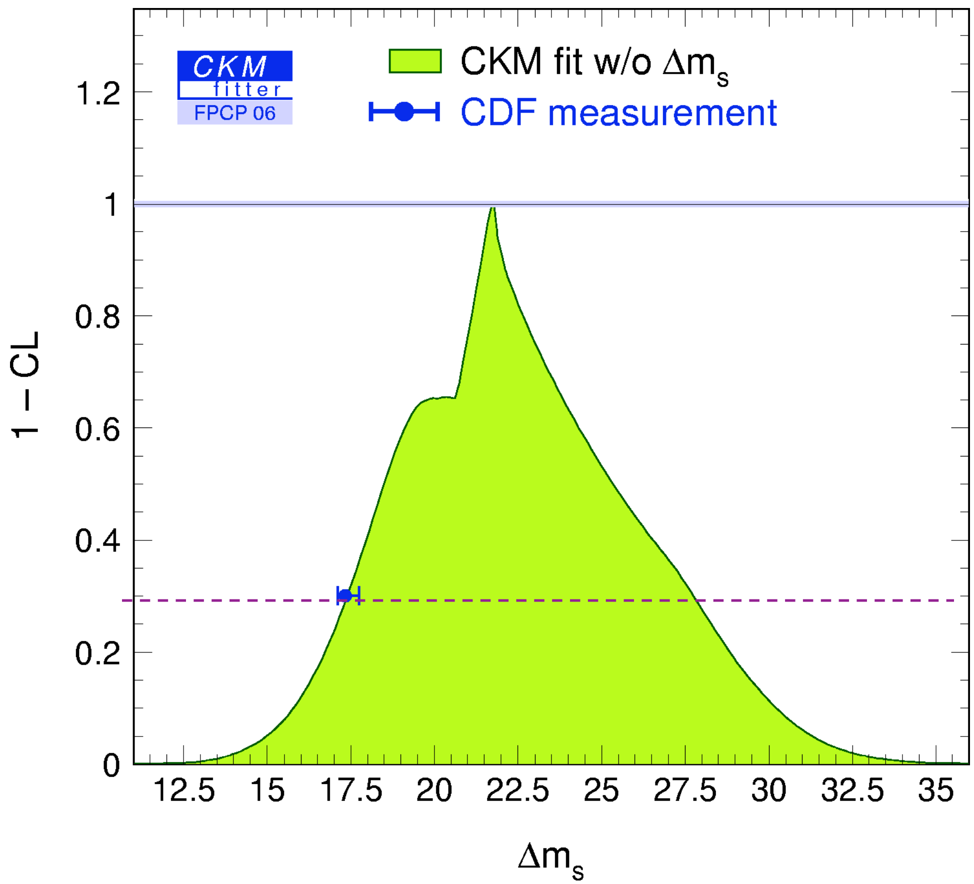
All relevant systematic uncertainties are common between hadronic and semileptonic samples

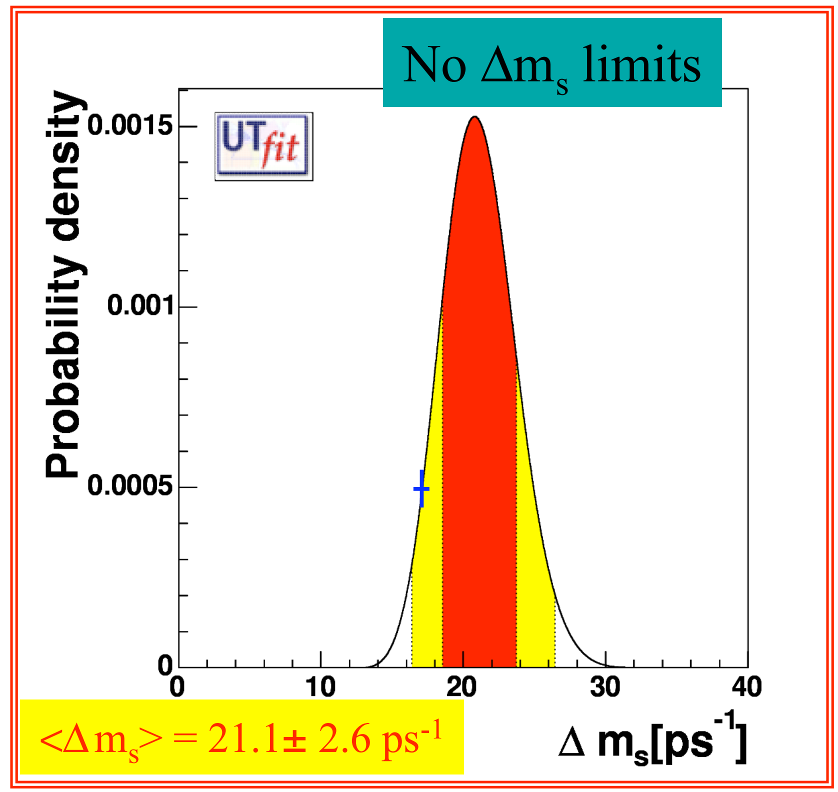
- systematic uncertainties from fit model evaluated on toy Monte Carlo
- have negligible impact
- relevant systematic unc. from lifetime scale

	Syst. Unc
SVX Alignment	0.04 ps^{-1}
Track Fit Bias	0.05 ps^{-1}
PV bias from tagging	0.02 ps^{-1}
All Other Sys	$< 0.01 ps^{-1}$
Total	0.07 ps^{-1}

$$\Delta m_s = 17.33 ^{+0.42}_{-0.21} \text{ (stat)} \pm 0.07 \text{ (syst) } ps^{-1}$$

CDF result vs expectations from non-xs measurements





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

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

- inputs:
  - $m(B^0)/m(B_s) = 0.9830$ (PDG 2006)
  - $\xi = 1.21\ ^{+0.047}_{-0.035}$ (M. Okamoto, hep-lat/0510113)
  - $\Delta m_d = 0.507 \pm 0.005$ (PDG 2006)

$$|V_{td}| / |V_{ts}| = 0.208\ ^{+0.008}_{-0.007}\ \text{(stat + syst)}$$

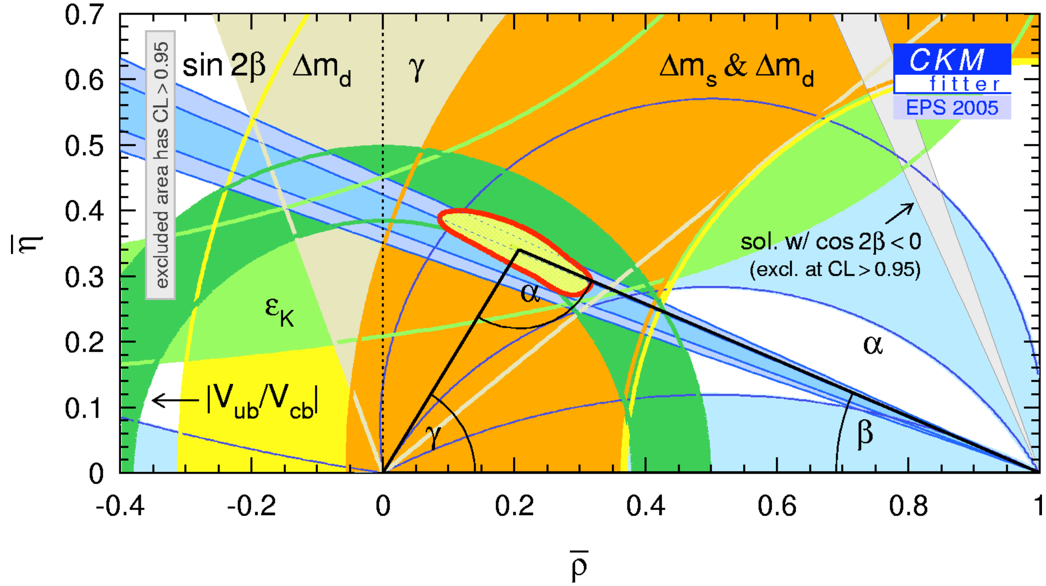
Uncertainty already dominated by lattice calculations rather than Δm_s !

- compare to Belle $b \rightarrow d\gamma$ (hep-ex/0506079):

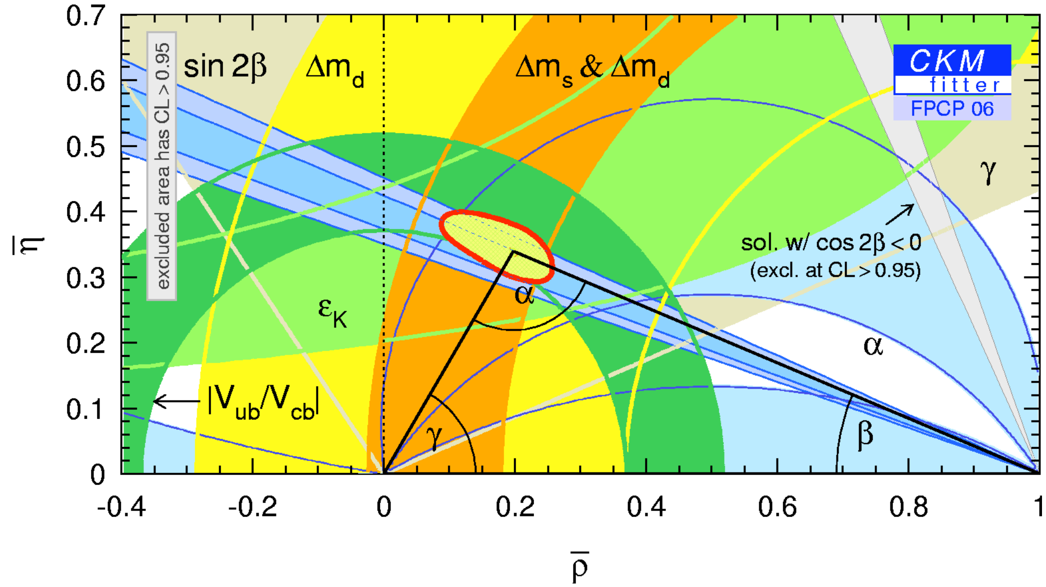
$$|V_{td}| / |V_{ts}| = 0.199\ ^{+0.026}_{-0.025}\ \text{(stat)}\ ^{+0.018}_{-0.015}\ \text{(syst)}$$

Impact of x_s on CKM triangle

- Before



- After



$\Delta\Gamma_s$

$\Delta\Gamma_s$

Want to probe *all* the parts of:

$$i\frac{d}{dt}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}$$

$$|B_H\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle$$

Heavier mass eigenstate

$$|B_L\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$$

Lighter mass eigenstate

$$\Delta m_s = M_H - M_L \sim 2|M_{12}|$$

$$\boxed{\Delta\Gamma_s = \Gamma_L - \Gamma_H} \sim 2|\Gamma_{12}|\cos\phi$$

$\phi \sim 0.3^\circ$ in SM

If CP conserved, *in mixing*

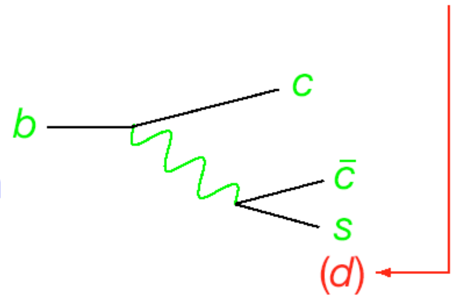
$$|B_L\rangle = |B^{\text{CP-even}}\rangle$$

$$|B_H\rangle = |B^{\text{CP-odd}}\rangle$$

$$\Gamma_s = \frac{\Gamma_L + \Gamma_H}{2} \quad ; \quad \bar{\tau} = \frac{1}{\Gamma_s} \quad ; \quad \tau_L = \frac{1}{\Gamma_L} \quad ; \quad \tau_H = \frac{1}{\Gamma_H}$$

How to measure

For B_d^0, analogous diagram
Cabibbo suppressed, Γ_{12} negligible



- Γ_{12} dominated by decay $b \to c\bar{c}s$ from decays into final states common to both B_s^0 $(\bar{b}s)$ and $\bar{B}_s^0$ $(b\bar{s})$

- $\Delta\Gamma_s$: CP-even final states, $\Delta\Gamma_s \uparrow$
  CP-odd final states, $\Delta\Gamma_s \downarrow$

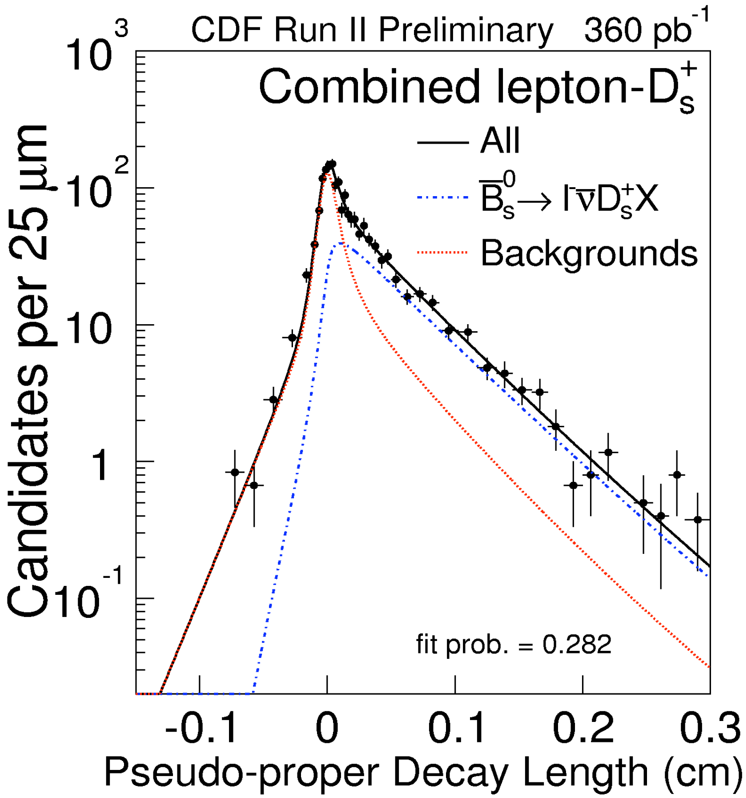
$B_s^0 \to D_s^+ D_s^-$ is pure CP even, and under various theoretical assumptions,
$B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ inclusive, also CP even to ~5%

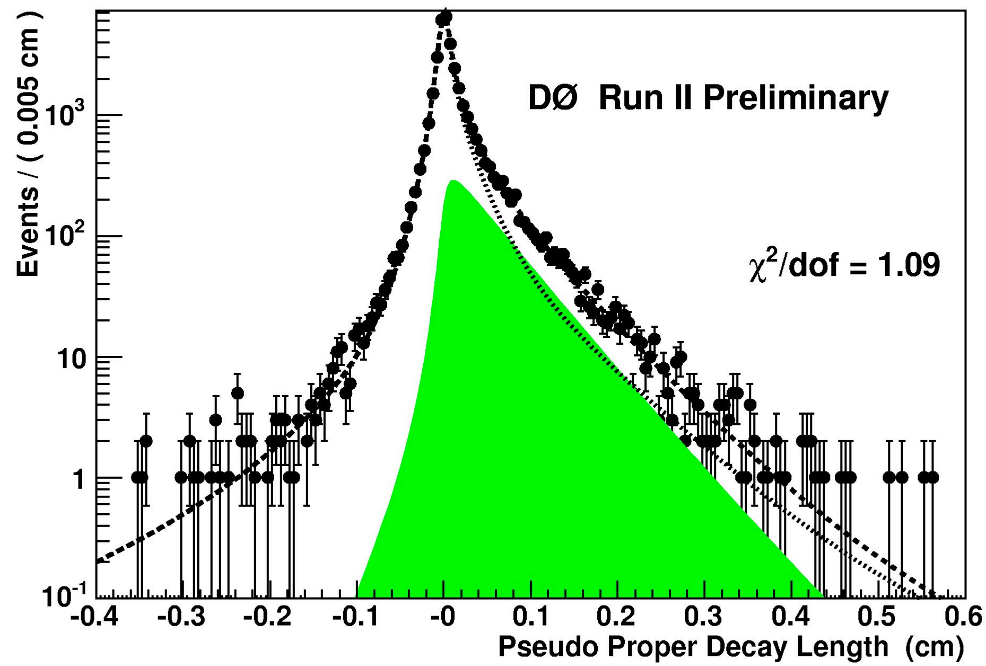
(Phys. Lett. **B316** (1993) 567)
Likely needs re-examination!!

$$\frac{\Delta\Gamma_s}{\Gamma_s} \sim \frac{2Br(B_s^0 \to D_s^{(*)+} D_s^{(*)-})}{1 - Br(B_s^0 \to D_s^{(*)+} D_s^{(*)-})/2} \qquad (\phi = 0)$$

Flavor-specific B_s Lifetime

- DØ and CDF measure B_s^0 lifetime in $B_s^0 \to D_s^- l^+ \nu\ X$





CDF *360 pb-1*

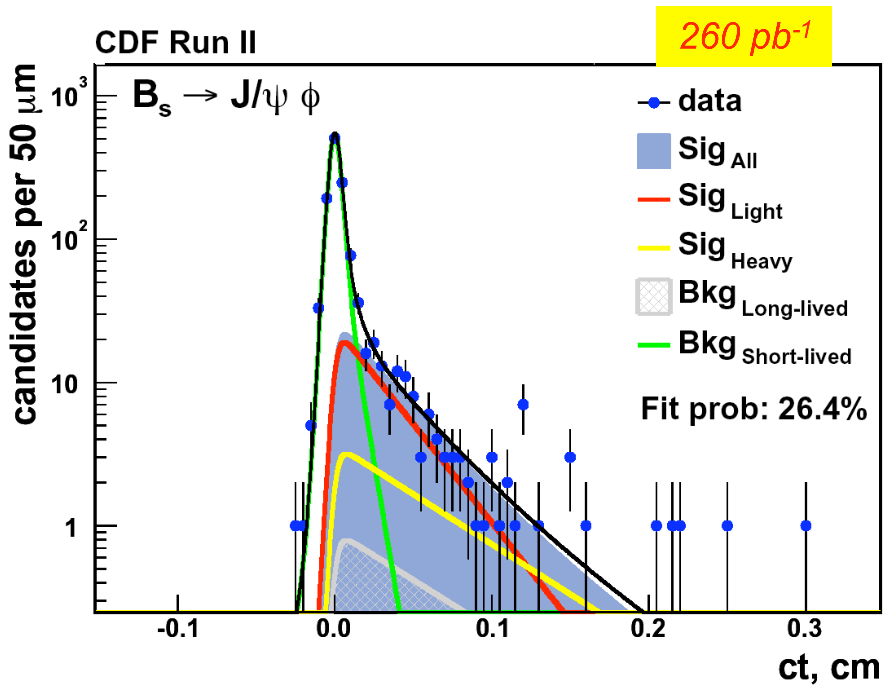
DØ *400 pb-1*

$\tau_{B_s^0} = 1.381 \pm 0.055\,(stat)^{+0.052}_{-0.046}\,(syst)\,\mathrm{ps}$	$\tau_{B_s^0} = 1.420 \pm 0.043\,(stat) \pm 0.057\,(syst)\,\mathrm{ps}$

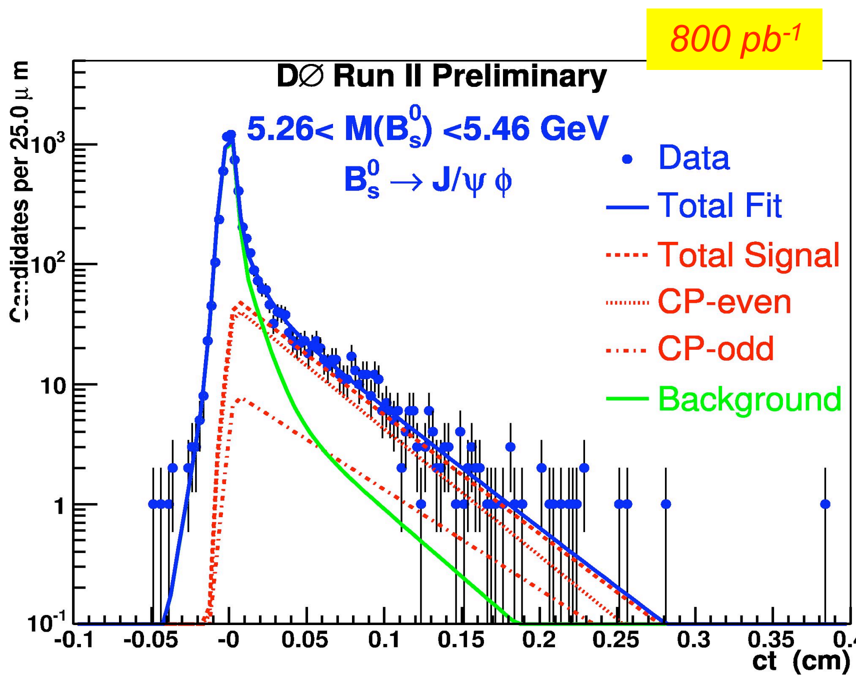
World’s best measurements

$\Delta\Gamma_s$ from $B_s \to J/\psi\,\phi$

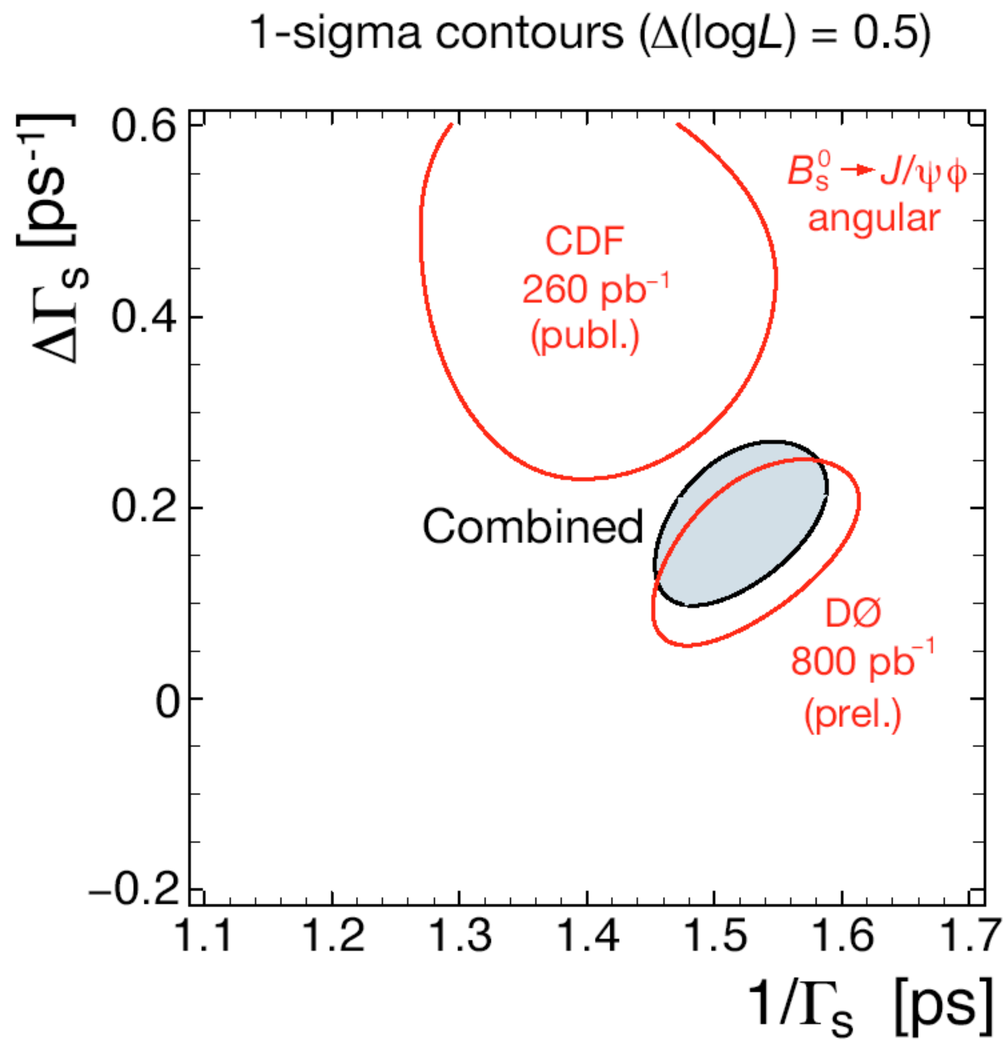
- Pseudoscalar → Vector - Vector
- Decay amplitude decomposed into 3 linear polarization states, with different angular distributions:
  - A_0 and $A_{||}$ = S + D wave ⇒ P even $\approx B_{s,\mathrm{Light}}$ (neglect CP violation)
  - $A_\perp$ = P wave ⇒ P odd $\approx B_{s,\mathrm{Heavy}}$ (neglect CP violation)
- Angular analysis separates CP eigenstates ⇒ measure two lifetimes



$$\Delta\Gamma = 0.47^{+0.19}_{-0.24}\,(\mathrm{stat}) \pm 0.01\,(\mathrm{syst})\,\mathrm{ps}^{-1}$$

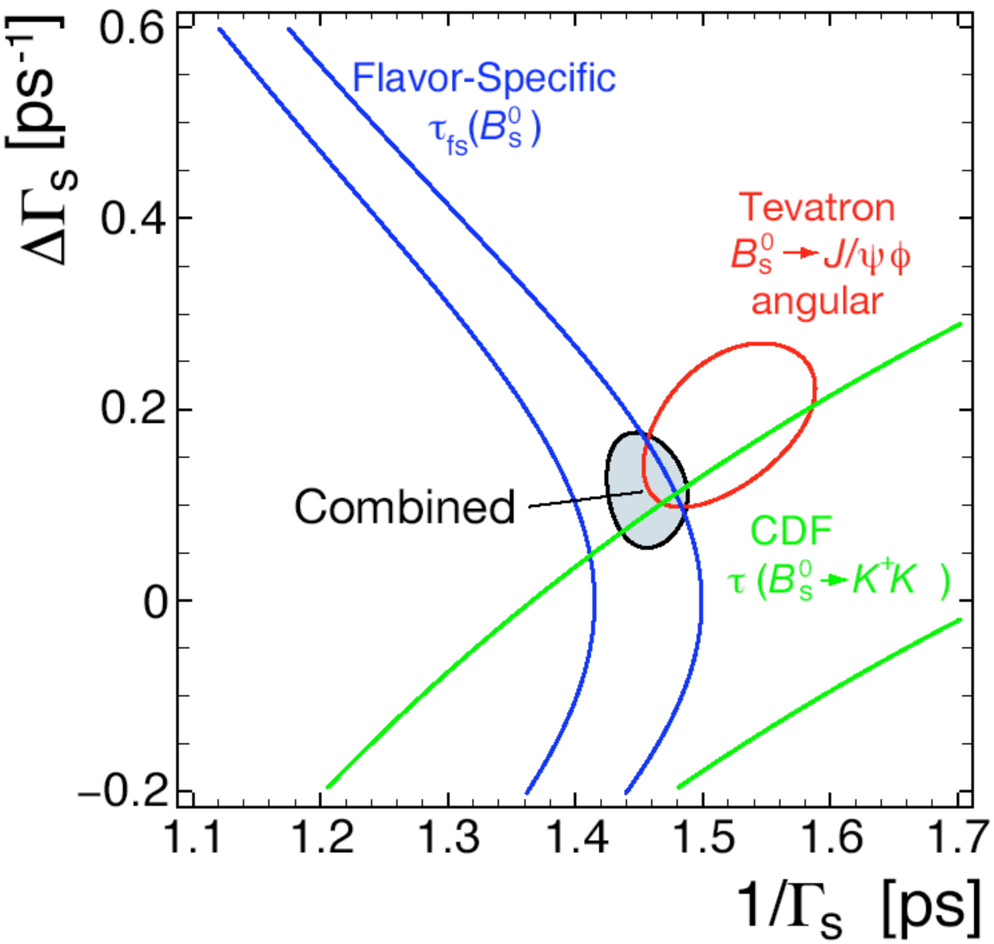


$$\Delta\Gamma = 0.15 \pm 0.10\,(\mathrm{stat})\,^{+0.03}_{-0.04}\,(\mathrm{syst})\,\mathrm{ps}^{-1}$$


1-sigma contours (Δ(logL) = 0.5)
$\Delta\Gamma_s$ [ps^{-1}]
0.6
0.4
0.2
0
−0.2
1.1
1.2
1.3
1.4
1.5
1.6
1.7
$1/\Gamma_s$ [ps]
$B_s^0 \to J/\psi\,\phi$
angular
CDF
260 pb^{-1}
(publ.)
Combined
DØ
800 pb^{-1}
(prel.)

Add flavor-specific and BsKK

1-sigma contours (Δ(log*L*) = 0.5)



$B_s \to D_s^{(*)+} D_s^{(*)-}$

- Branching ratio measured in the decay mode:

$$B_s^0 \to D_s^{(*)+} D_s^{(*)-}$$

$D_s^{(*)+} \to \phi\,\mu^+\nu$ Semileptonic

$D_s^{(*)-} \to \phi\,\pi^-$ Hadronic

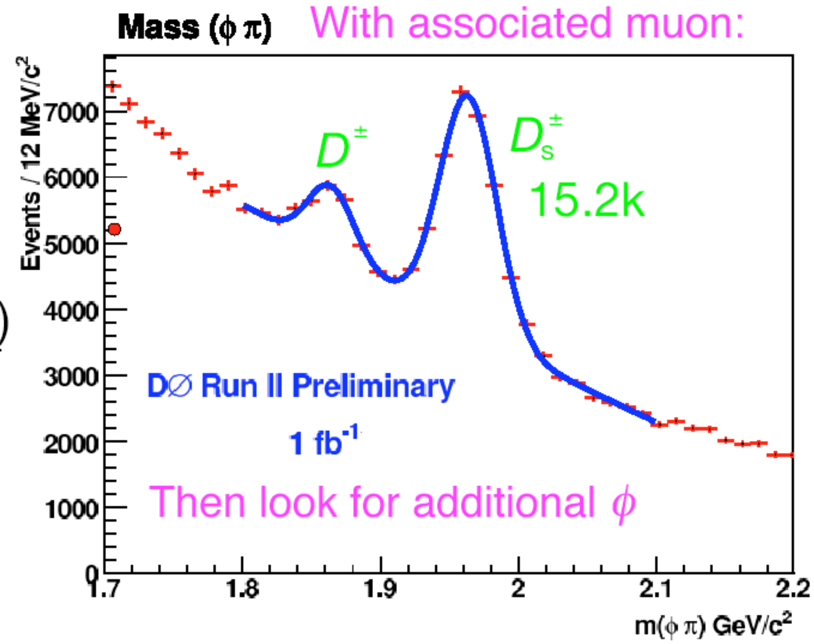
$$\phi \to K^+K^-$$

- Normalized to:

$$B_s^0 \to D_s^{(*)+}\mu^-\nu$$

$$D_s^{(*)+} \to \phi\,\pi^+$$

With associated muon:



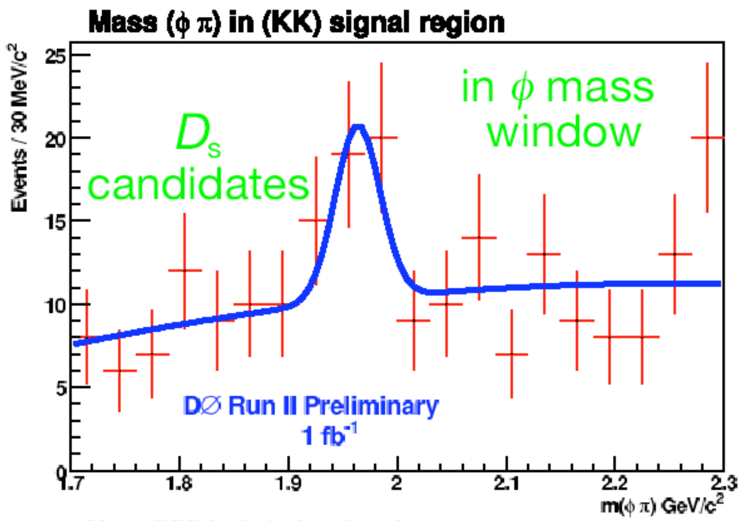
Mass and width used as input parameters in following fits

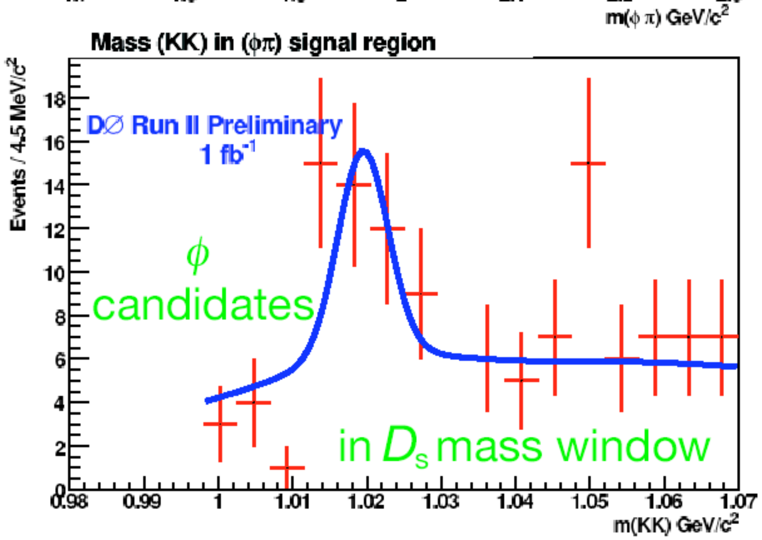
- Measure ratio:

$$R = \frac{Br(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) \cdot Br(D_s \to \phi\,\mu\,\nu)}{Br(B_s^0 \to \mu\,\nu\,D_s^{(*)-})}$$

(many systematics cancel in the ratio)

$B_s \rightarrow D_s^{(*)+} D_s^{(*)-}$





Simultaneous unbinned likelihood fit, including in the mass sidebands

- Number found: $N(\mu \phi D_s) = 19.3 \pm 7.8$
- Backgrounds:
  - $B \rightarrow D_s^{(*)+} D_s^{(*)-} K X$ 0.44 ± 0.30
  - $B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-} X$ suppressed
  - $B_s^0 \rightarrow \mu \nu D_s^{(*)} \phi X$ 1.27 ± 1.14
  - $c\bar{c} \rightarrow \mu \phi D_s^{(*)}$ lifetime cuts
- Use new $Br(D_s \rightarrow \phi \pi)$ from BaBar, combined w/ PDG

$$Br(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}) = 0.071 \pm 0.032 \text{ (stat)} {}^{+0.029}_{-0.025} \text{ (syst)}$$

$B_s \to D_s^+ D_s^-$

- Branching ratio measured in the decay mode:

$$B_s^0 \to D_s^+ D_s^-$$

$D_s^+ \to \phi\pi^+$ $(3\pi, K^*K)$ Hadronic

$D_s^- \to \phi\pi^-$ $(3\pi, K^*K)$ Hadronic

$$\phi \to K^+K^-$$

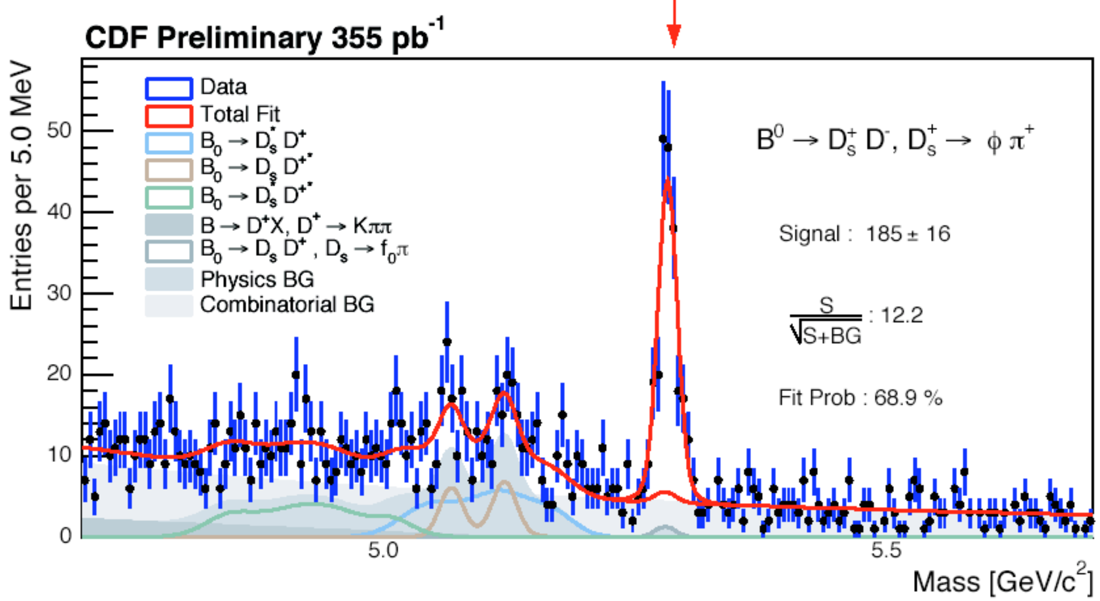
- Normalized to:

$$B_s^0 \to D_s^+ D^-$$

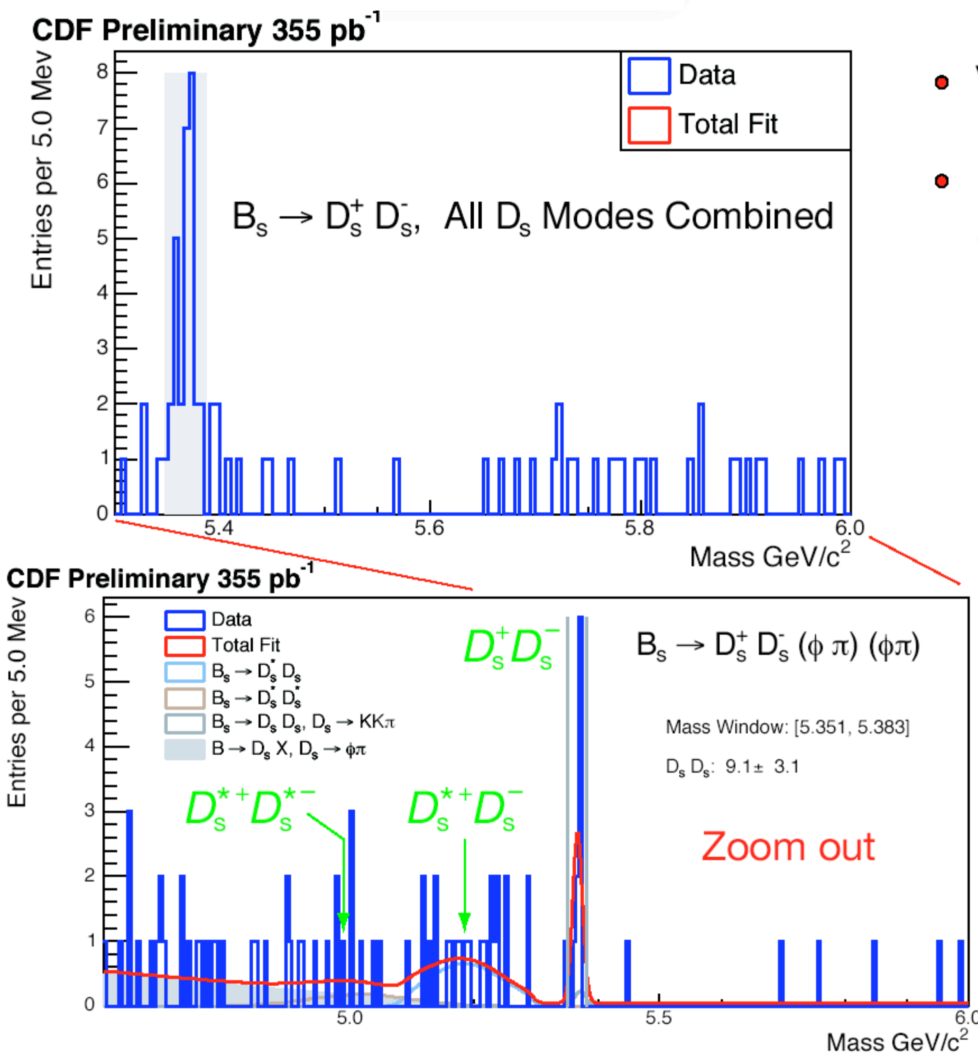
$D^- \to K\pi\pi$

$D_s^+ \to \phi\pi^-$ $(3\pi, K^*K)$

- Plus many more channels with similar topology studied in detail with higher statistics (exclusive hadronic, two secondary resonances with 3 tracks each)



$B_s \rightarrow D_s^+ D_s^-$



- Number signal 23.5 ± 5.5 cand.
- Very clean! Negligible backg.
- Use Br($D_s \rightarrow \phi\pi$) from PDG
  (waiting for PDG combo w/ BaBar)

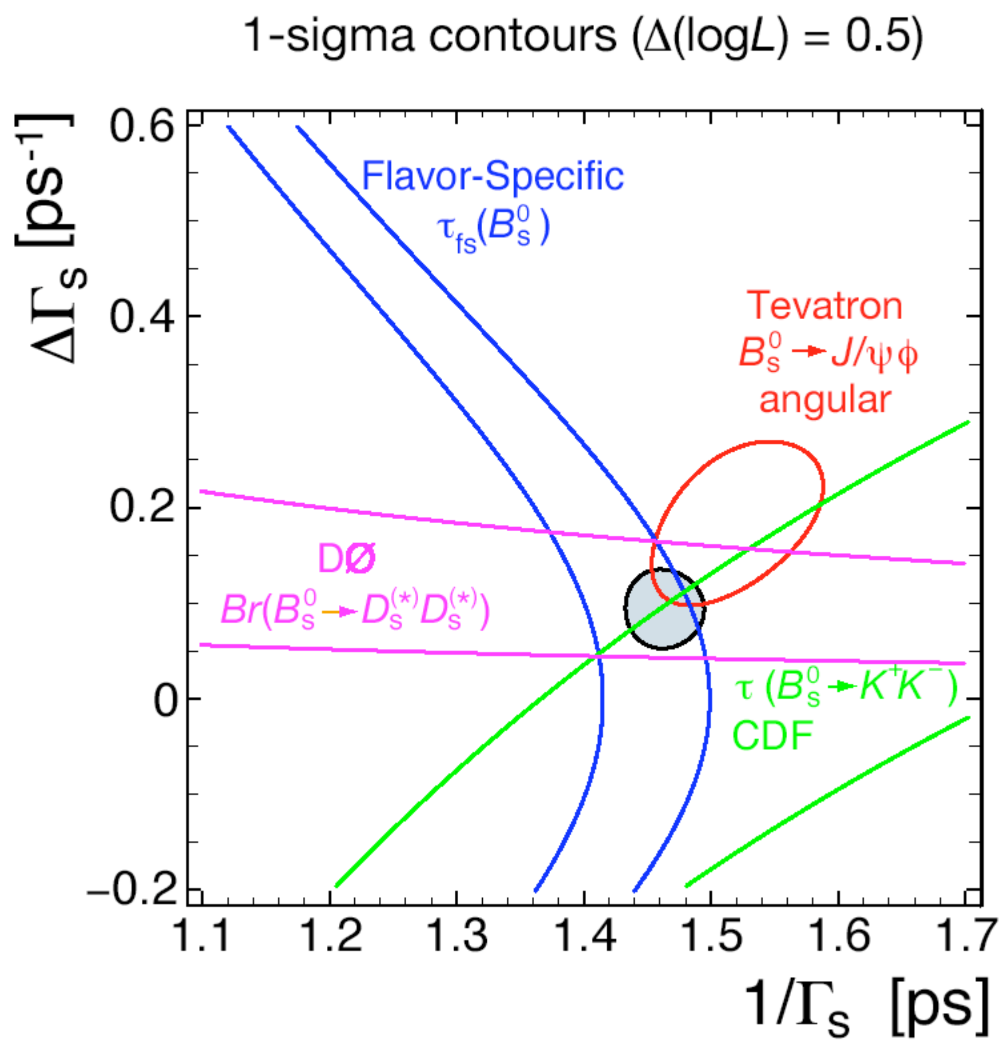
$$\frac{Br(B_s^0 \rightarrow D_s^+ D_s^-)}{Br(B_s^0 \rightarrow D_s^+ D^-)} =$$

$$= 1.67 \pm 0.41 \text{ (stat.)} \pm 0.12 \text{ (syst.)} \pm 0.24\ (f_s/f_d) \pm 0.39\ (Br_{\phi\pi})$$

- First observation of this fully reconstructed decay
- CDF working on its use to extract $\Delta\Gamma_s$
  (hints for other modes there, good prospects with 1 fb^{-1})

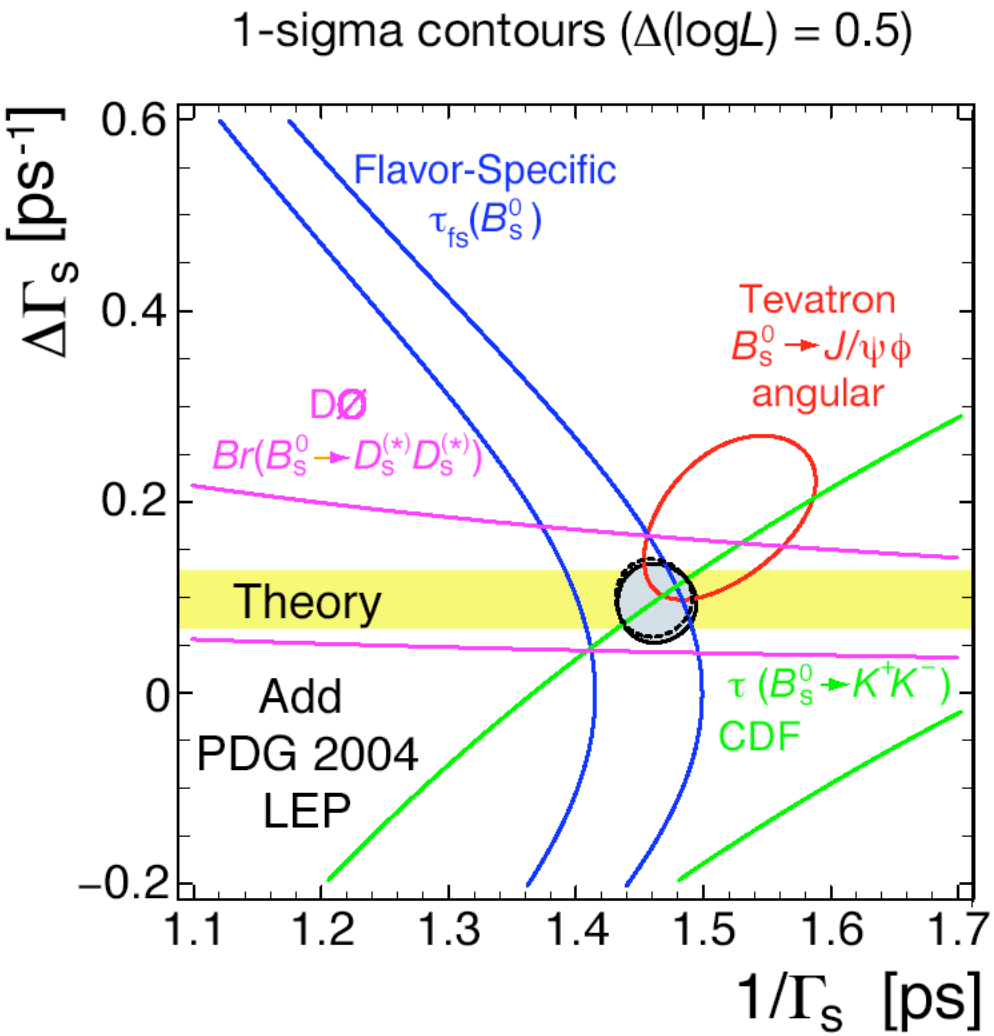
[Van Kooten, FPCP06]

Adding D_sD_s



[Van Kooten, FPCP06]

Full



- PDG 2004 (LEP) includes ALEPH measurement of $Br(B_s^0 \to D_s^{(*)+} D_s^{(*)-})$
- Theoretical prediction:

$$\Delta\Gamma_s = 0.10 \pm 0.03\ \text{ps}^{-1} \left(\frac{f_{B_s}}{260\ \text{MeV}}\right)^2$$

(Update (Nierste) of Phys.Lett. **B459** 631,1999)

- Unofficial world average

$$\Delta\Gamma_s = 0.097\,^{+0.041}_{-0.042}\ \text{ps}^{-1}$$

$$\bar{\tau} = \frac{1}{\Gamma_s} = 1.461 \pm 0.030\ \text{ps}$$

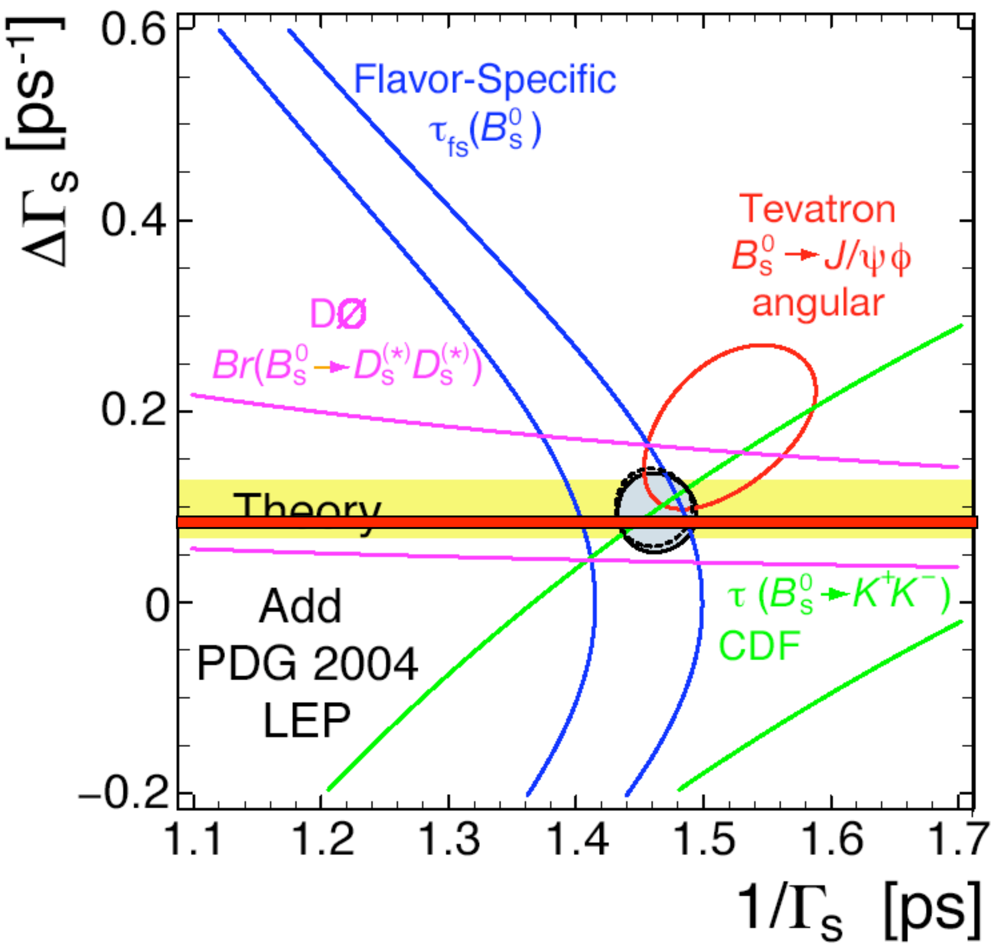
2.4σ from zero

$$\tau_L = \frac{1}{\Gamma_L} = 1.364\,^{+0.047}_{-0.045}\ \text{ps}$$

$$\tau_H = \frac{1}{\Gamma_H} = 1.573\,^{+0.060}_{-0.061}\ \text{ps}$$

Add Δm_s

1-sigma contours ($\Delta(\log L) = 0.5$)



Even more unofficial:
use as input:

$$\frac{\Delta\Gamma_s}{\Delta m_s} = (47 \pm 8) \times 10^{-4}$$

(SM prediction, see prev. slide)

and the CDF measurement:

$$\Delta m_s = 17.33^{+0.42}_{-0.21} \pm 0.07 \text{ ps}^{-1}$$

to derive the expectation:

$$\Delta\Gamma_s = 0.081 \pm 0.014$$

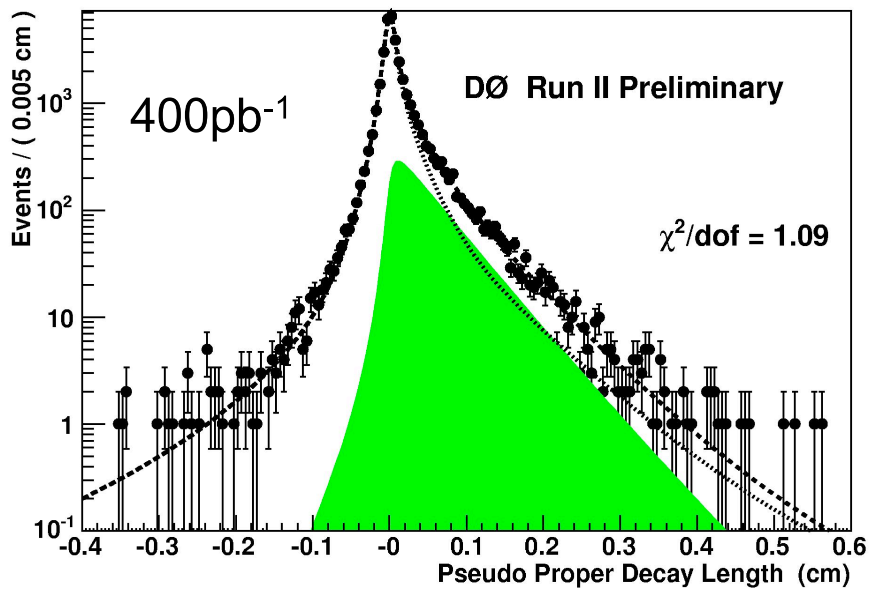
Conclusions & Prospects

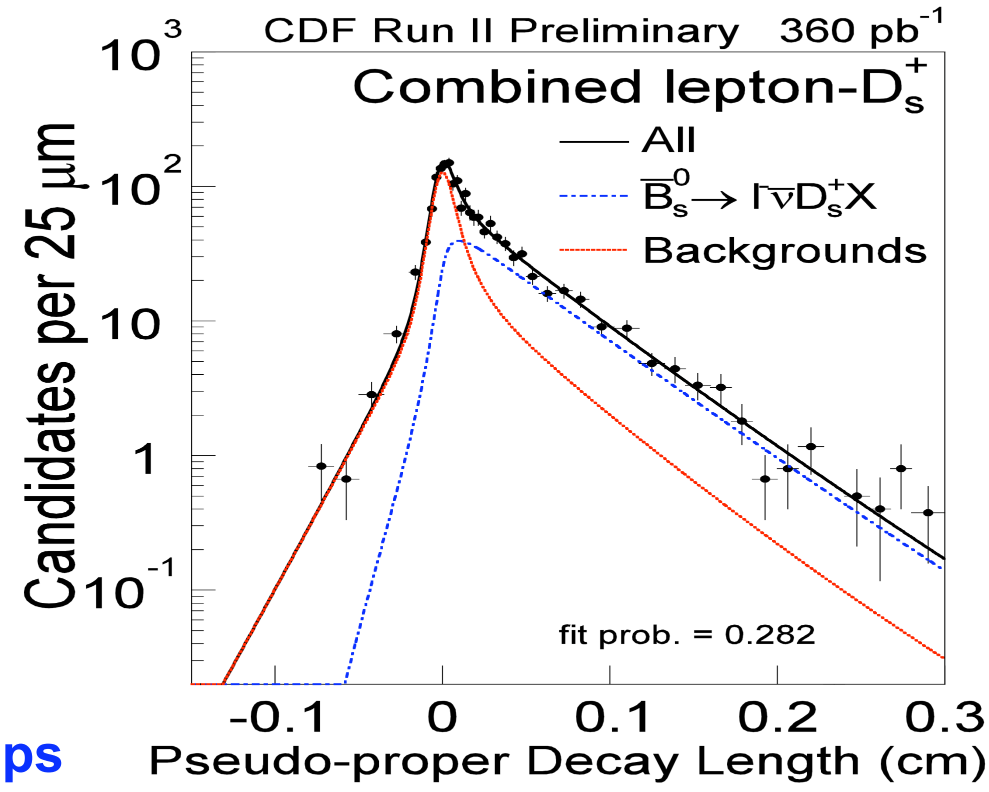
- After a long quest, Bs oscillations have been seen and precisely measured.
- Further data will soon confirm results at larger significance level, and yield even more precise Δm_s
- $\Delta\Gamma_s$ knowledge is growing rapidly - hope to see effect soon.
- Tevatron demonstrated feasibility of many other crucial B measurements in the hadronic environment
  - Precision CP asymmetries ($B^0 \to K^+\pi^-$)
  - Rare decays, both leptonic and adronic
  - Large clean signals of $B^+ \to D^0\pi^+$: expect γ measurements from $B^+ \to D^0K^+$ soon
- Experimentalist's luck: Δm_s is "small" and SSKT is "powerful"
  $\Rightarrow$ easier to tackle next round: time-dependent Bs measurements:
  - Time-dependent Bs asymmetries: $B_s \to KK$ (γ), $B_s \to J/\psi\ \varphi$ (β_s)
  - Angle γ at tree-level from $B_s \to D_sK$

BACKUP

B_s Lifetime

D0 and CDF measure B_s lifetime in semileptonic decay: $B_s \rightarrow l^+ \nu\, D_s^- X$





D0:

$\tau(B_s)$=1.420±0.043(stat) ±0.057(syst) ps

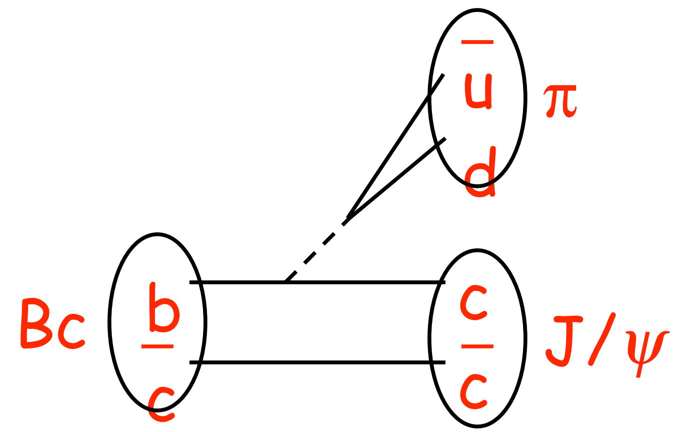
(Best in the world)

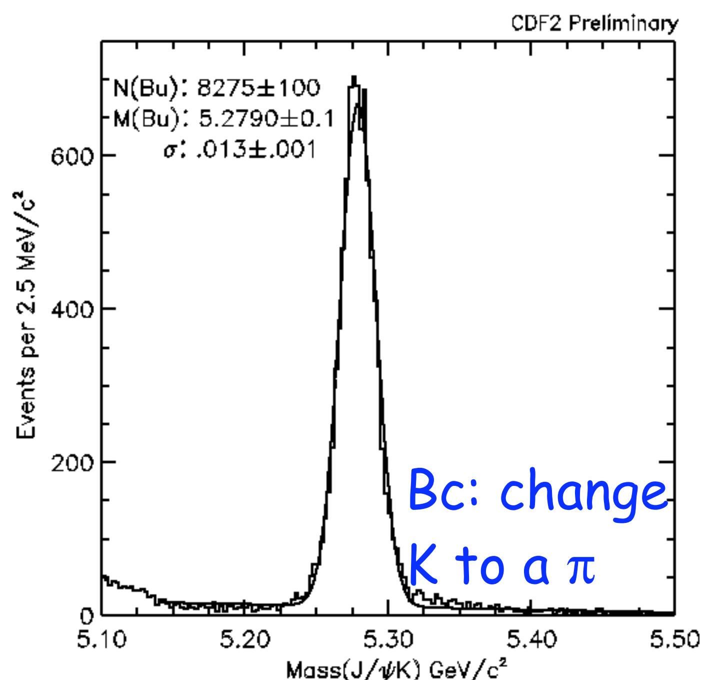
CDF:

$\tau(B_s)$=1.381±0.055(stat) $\pm^{0.052}_{0.046}$(syst) ps

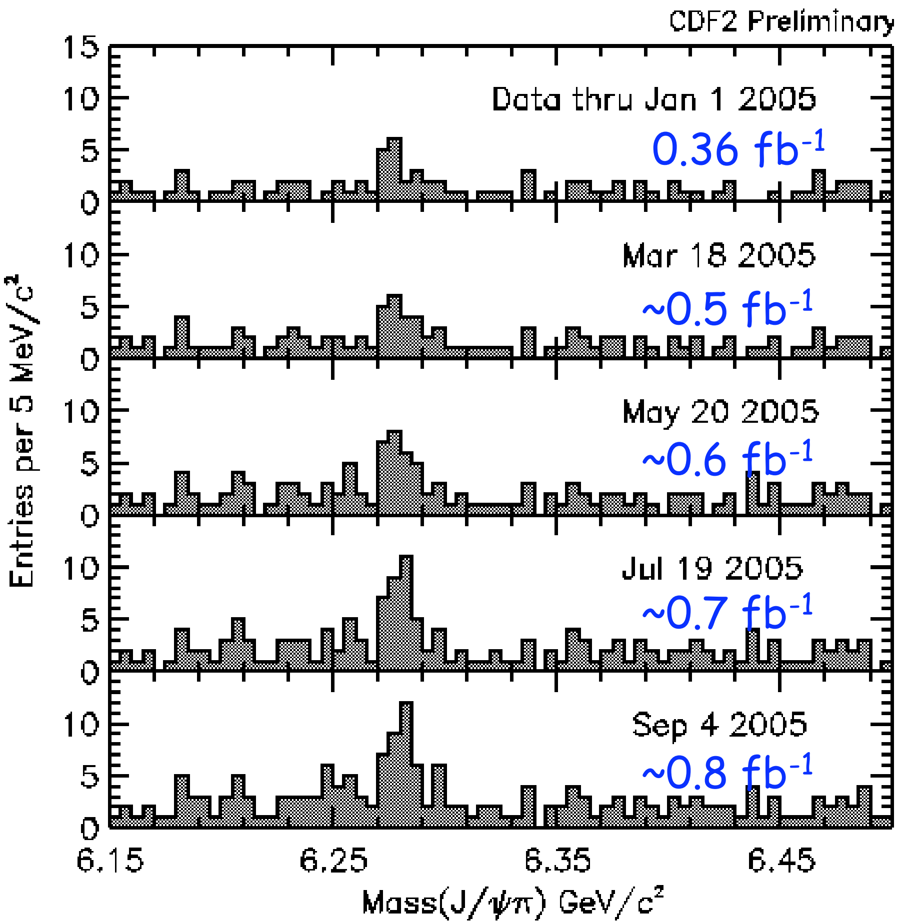
B_c Mass Measurement

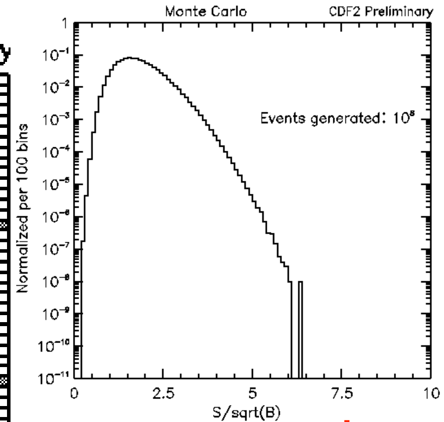
- B_c has short lifetime and small production rate
- Full reconstruction allows for precise mass measurement
- New CDF analysis
  - Tune B_c selection on reference $B^+ \to J/\psi K^+$ data
  - After selection cuts are fixed, "open box"
  - Wait for events to become a significant excess
  - Measure properties of the B_c





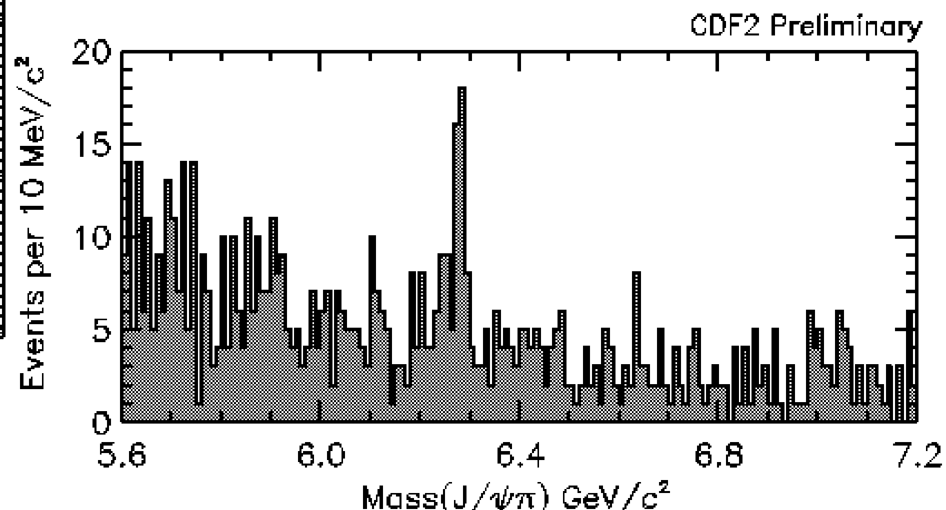
B_c Mass Measurement





Num(events)$_{FIT}$= 38.9 sig 26.1 bkg between 6.24-6.3

Significance > 6σ over search area

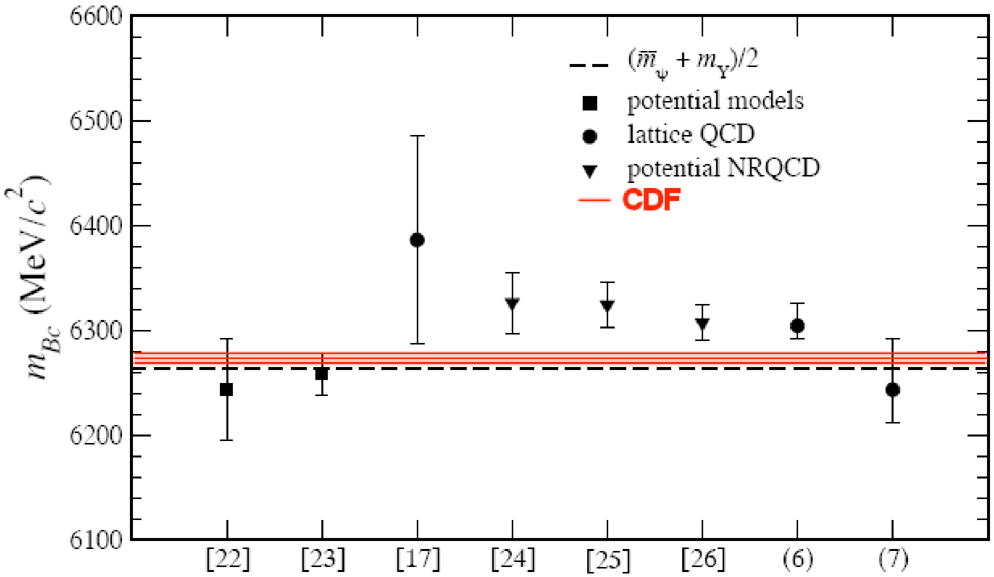


Mass(Bc) = 6275.2 +/- 4.3 +/- 2.3 MeV/c^2

Most precise measurement of Bc mass

B_c Lattice Calculations

- Recent lattice calculations predict B_c mass with ~20 MeV precision !!



$M(Bc)_{CDF}$ = 6275.2 ± 4.3 ± 2.3 MeV/c^2 (hadronic)

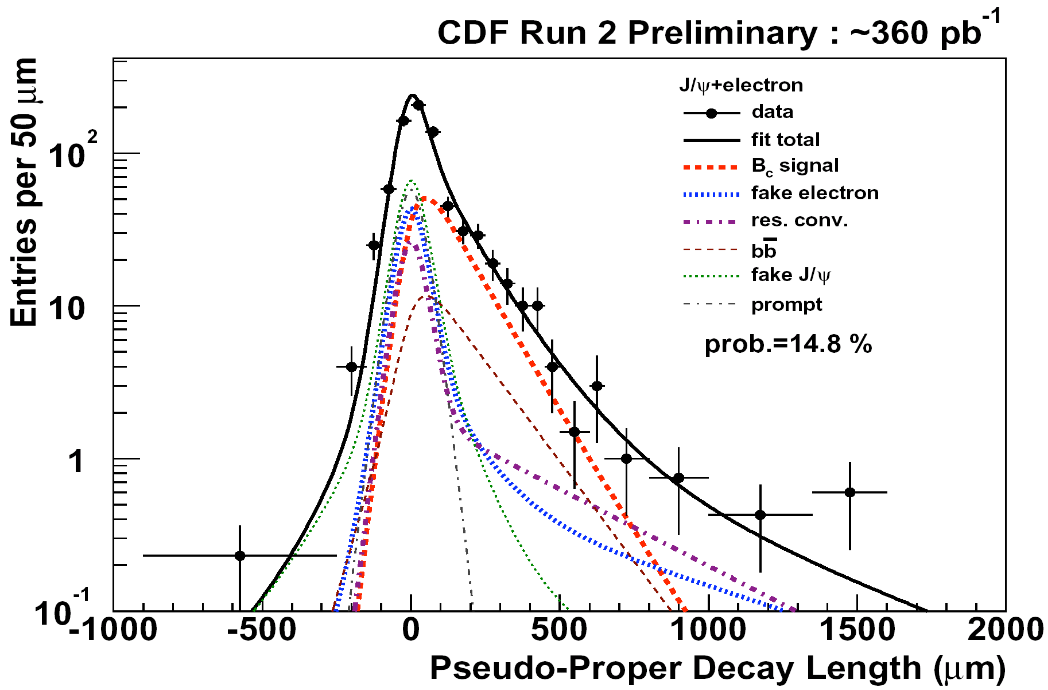
$M(Bc)_{D0}$ = 5950 ± 140 ± 340 MeV/c^2 (semileptonic)

$M(Bc)_{LAT}$ = 6304 ± 12 $^{+18}_{-0}$ MeV/c^2

I.F. Allison et al., PRL 94 172001 (2005)

B_c Lifetime

- Bc lifetime extracted from $B_c \rightarrow J/\psi\, e\, \nu$ sample



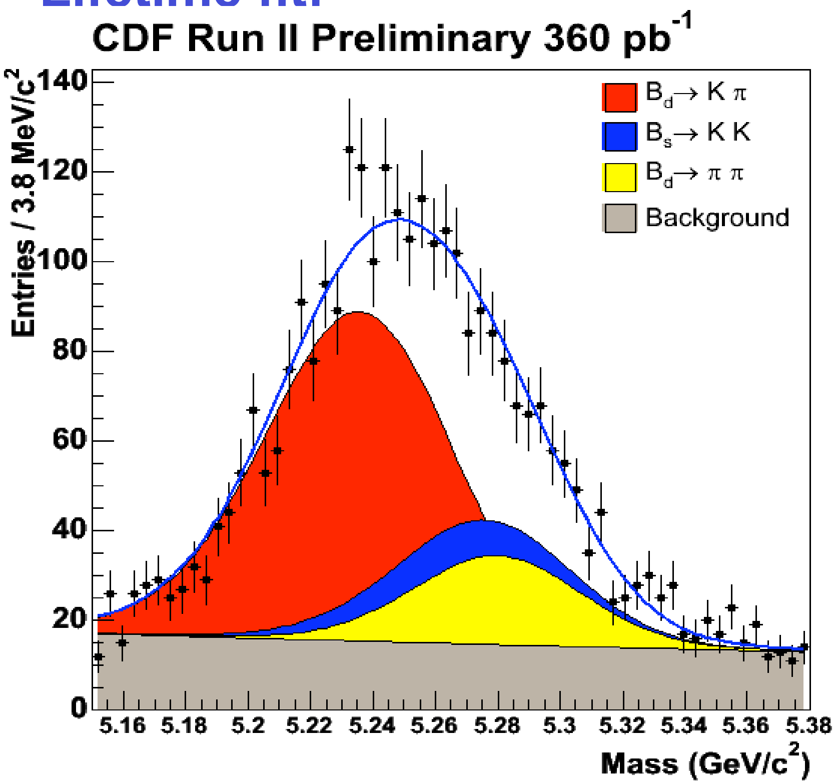
- More stat than hadronic mode
- But also more background too

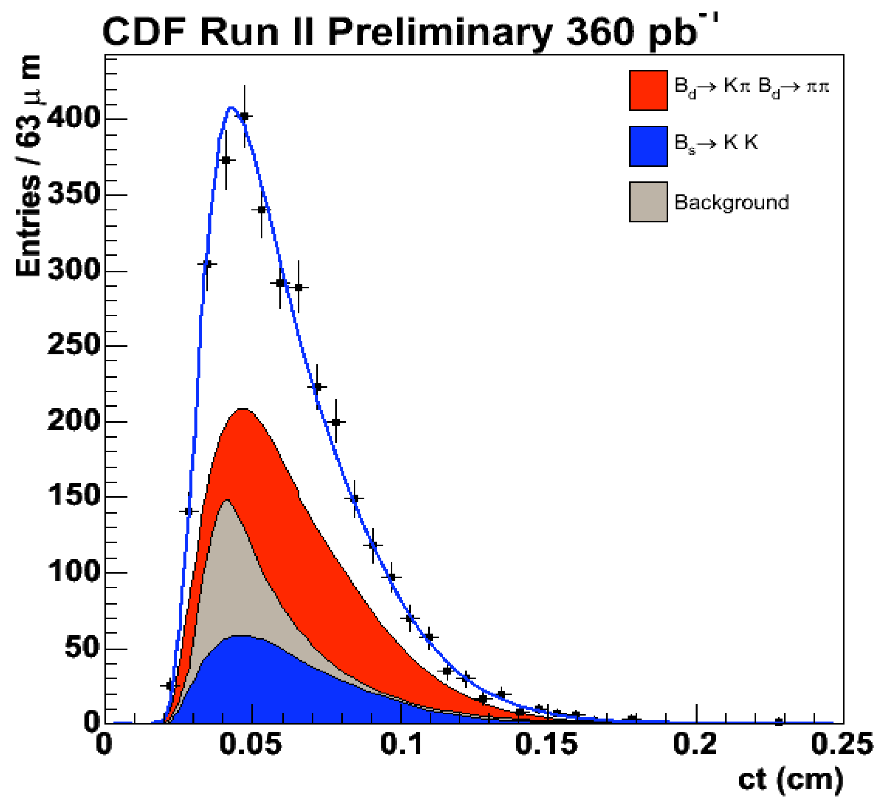
- CDF B_c lifetime measured with J/ψ+e channel (360pb^{-1})
  0.474 +0.074/-0.066 ±0.033 ps (Best in the world)
- D0 B_c lifetime measured with $J/\psi+\mu$ channel (210pb^{-1})
  0.448 +0.123/-0.096 ±0.121 ps
- Theoretical prediction: 0.55 ± 0.15 ps

V. Kiselev, hep-ph/0308214

Extract $\Delta\Gamma$ from $B_s \rightarrow K^+ K^-$ Lifetime

- Measurement of $B_s \rightarrow K^+K^-$ lifetime ($=\tau_L$) in $360 pb^{-1}$
- Mass fit as in BR and CP measurements
- Lifetime fit:





- Extraction of $\Delta\Gamma(CP)/\Gamma(CP)$
  - This measurement gives $c\tau_L = 458 \pm 53 \pm 6\ \mu m$
  - HFAG average gives weighted average: $(\tau_L^2 + \tau_H^2)/(\tau_L + \tau_H)$
  - Extract τ_H
  - Thus derive $\Delta\Gamma/\Gamma = 0.080 \pm 0.23\ (stat) \pm 0.03\ (syst)$

Summary of $\Delta\Gamma_s$ / Γ_s Measurements

- **CDF $B_s \rightarrow K^+K^-$ (measure τ_L): 360pb^{-1}**

  $\Delta\Gamma/\Gamma = -0.080 \pm 0.23$ (stat) ± 0.03 (syst)

- **D0 $B_s \rightarrow J/\psi\,\phi$ (measure τ_H, τB_s): 220pb^{-1}**

  $\Delta\Gamma/\Gamma = 0.24 \pm^{0.28}_{0.38}$ (stat) $\pm^{0.03}_{0.04}$ (syst)

  PRL 95 171801 (2005)

- **CDF $B_s \rightarrow J/\psi\phi$ (measure τ_L and τ_H): 210pb^{-1}**

  $\Delta\Gamma/\Gamma = 0.65 \pm^{0.25}_{0.33}$ (stat) ± 0.01 (syst)

  PRL 94 102001 (2005)

Both CDF and D0 have >x2 more data to analyze