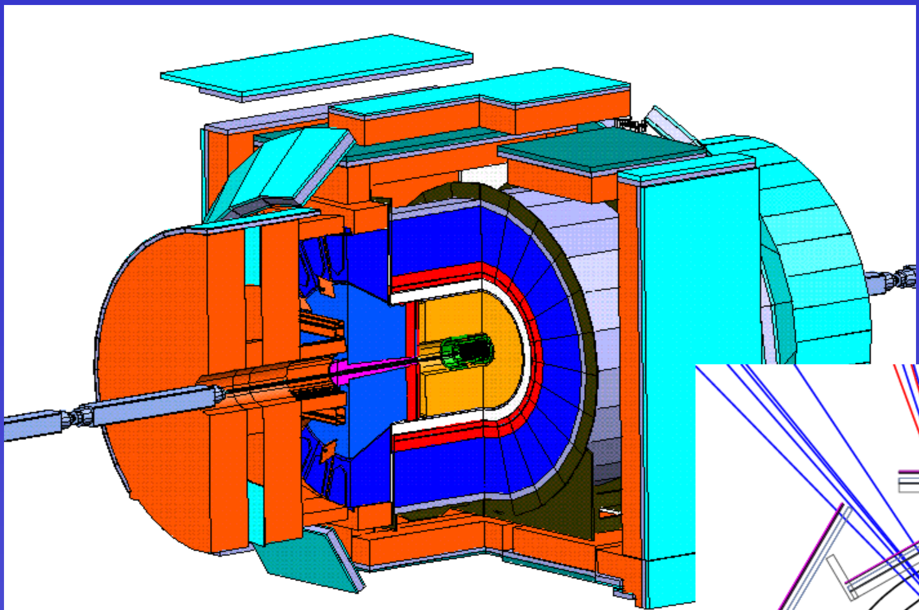
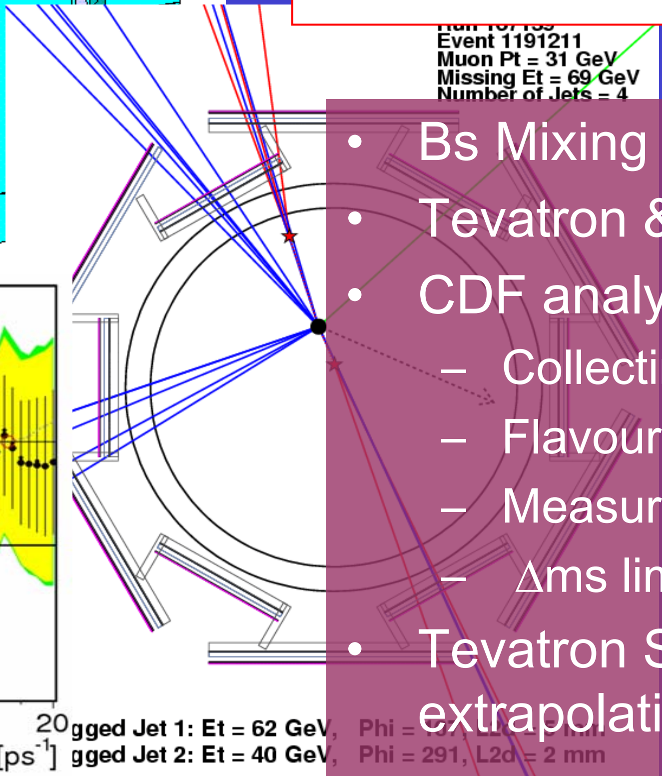
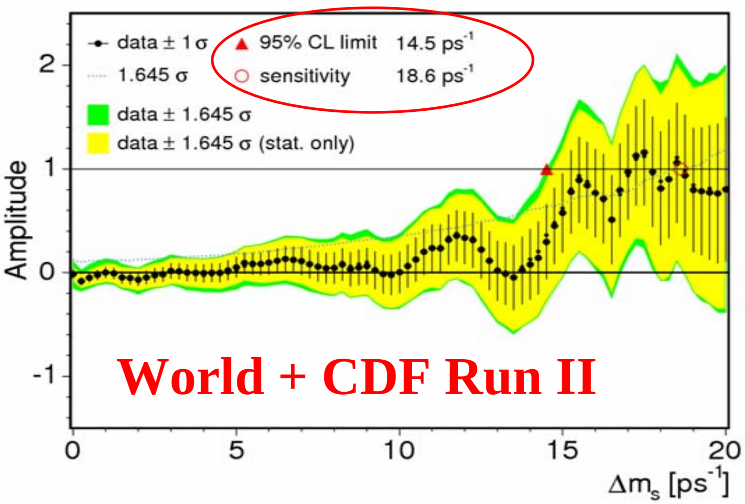
B^0 mixing at CDF

Marco Rescigno – INFN/Roma

Beauty 2005







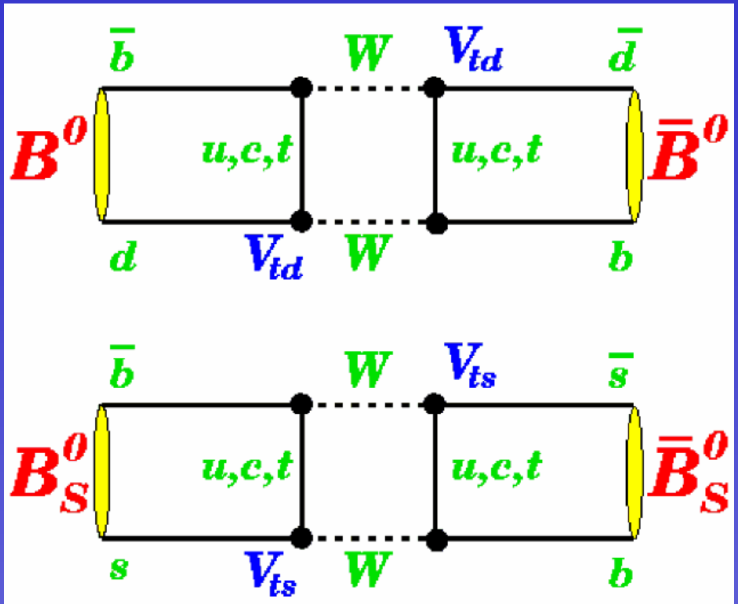
- Bs Mixing predictions
- Tevatron & CDF
- CDF analysis
  - Collecting B(s)
  - Flavour Tagging
  - Measuring Δm_d
  - Δms limit
- Tevatron Sensitivity extrapolation

B^0 Flavour Oscillations

Flavour oscillations occur through 2^{nd} order weak interactions

$$\Delta m_q = \frac{G_F^2 m_W^2 \eta S(m_t^2/m_W^2)}{6\pi^2} m_{Bq} f_{Bq}^2 B_{Bq} \left|V_{tq}^* V_{tb}\right|^2$$

Δm_d (exp.)= $0.510 \pm 0.005\ ps^{-1}$ *(HFAG 2005)*



<u>Lattice-QCD:</u>

$f^2_{Bd}B_{Bd} = (223 \pm 33 \pm 12)$ MeV

$f^2_{Bs}B_{Bs} = (276 \pm 38)$ MeV

→ $|V_{td}|$ determined at ~15%

<u>But in the ratio uncertainties cancels:</u>

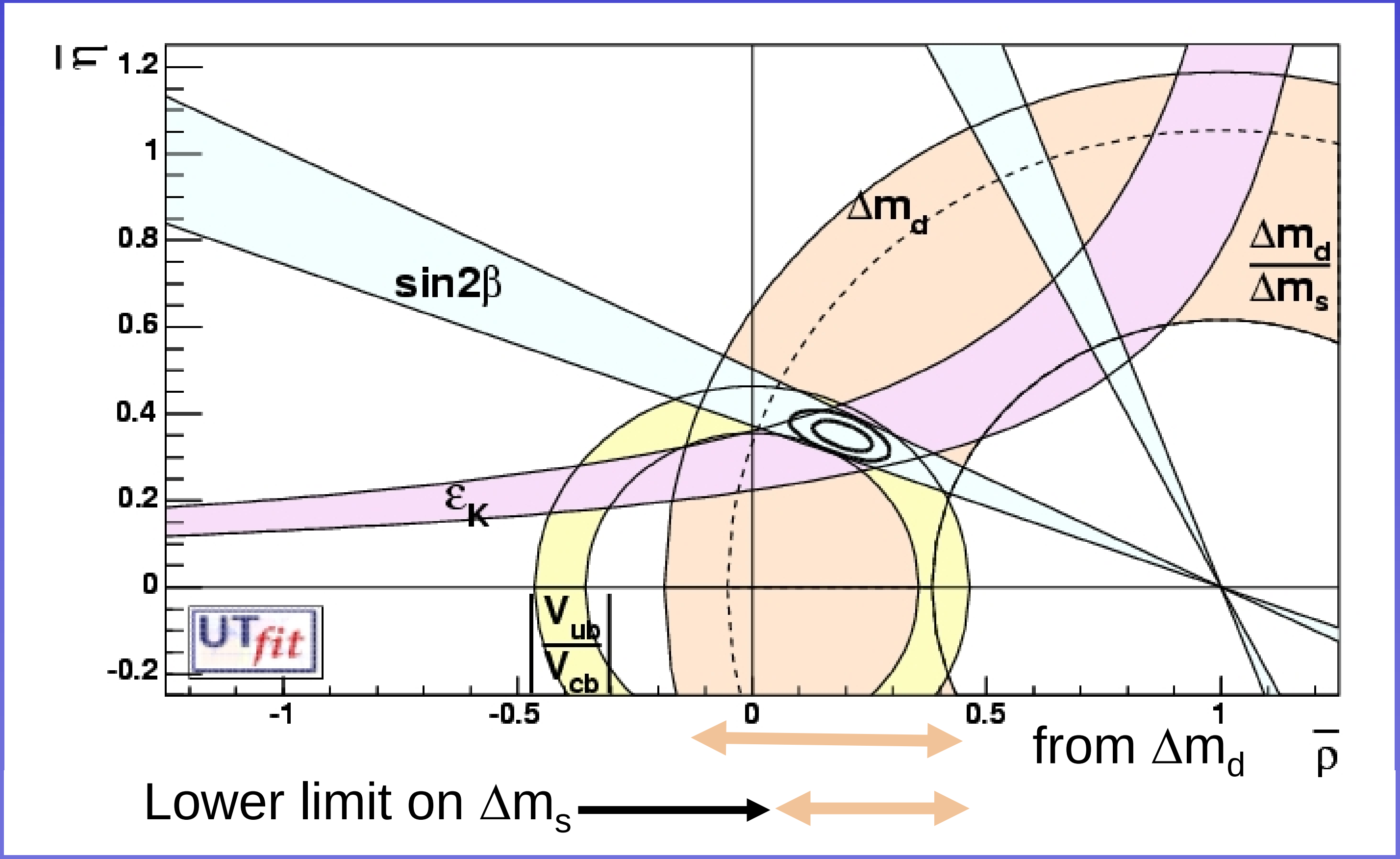
$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \frac{f_{Bs}^2 B_{Bs}}{f_{Bd}^2 B_{Bd}} \frac{|V_{ts}|^2}{|V_{td}|^2} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$

Measuring $\Delta m_s/\Delta m_d$ tests $|V_{ts}|/|V_{td}|$ with ~ 5% theory error

$\xi = 1.24 \pm 0.04 \pm 0.06$

Unitarity Triangle & Δm_s

- Brown Band: Δm_d measurement: ~15% uncertainty
- Dashed circle: lower limit on $\Delta m_s / \Delta m_d$ → Upper Limit on $|V_{td}|$
  - The lower bound on Δm_s already gives a constraint to Unitarity Triangle
- http://utfit.roma1.infn.it



CKMfitter's version

CKM fit

Input from
$|V_{ub}/V_{cb}|$, Δm_d, ε_K, $\sin 2\beta$, $\cos 2\beta$, α and γ:

$\Delta m_s = 20.4 \pm 2.8$ ps^{-1}
[15.1, 26.3] @ 95% CL

include also Δm_s limit:

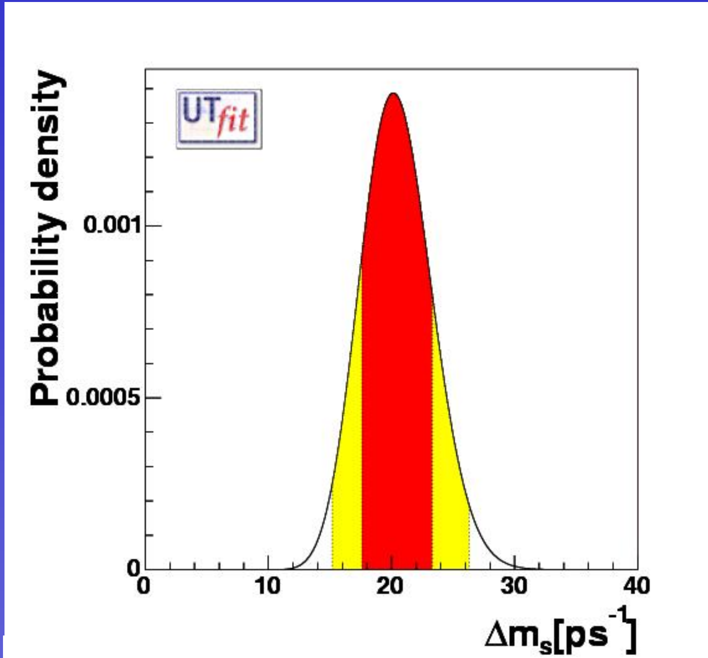
$\Delta m_s = 18.9 \pm 1.7$ ps^{-1}
[15.7, 23.0] @ 95% CL

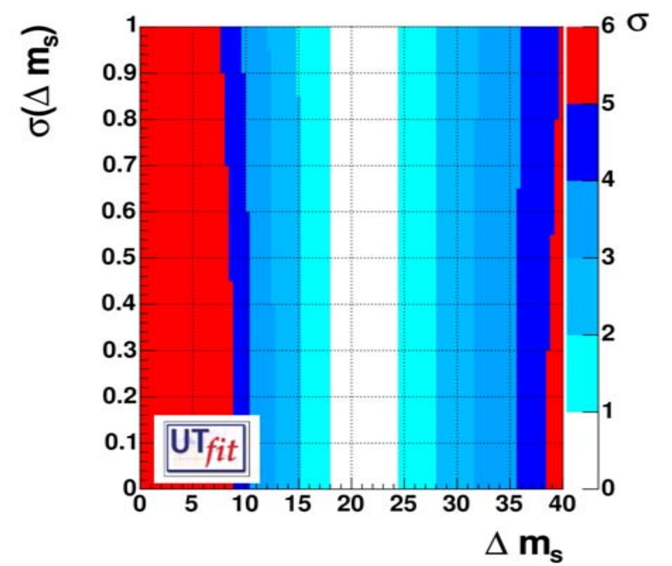
A very narrow shooting range for collider experiments!

New Physics @ 3σ **for $\Delta m_s > 31$** ps^{-1}

b-s sector much less constrained (yet) than b-d

Large New Physics contribution to B_s mixing and its phase still possible!



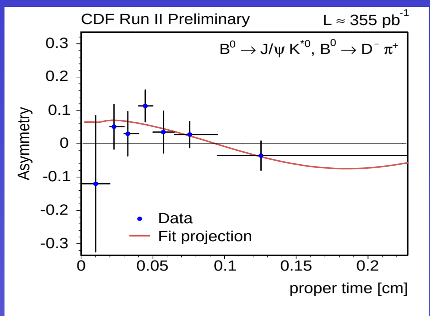


compatibility plot

Outline/RoadMap to Δm_s

Recall: expression for significance in a mixing measurement

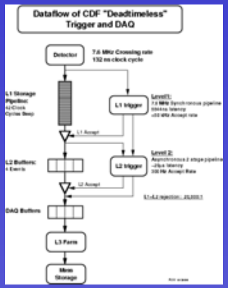
$$Significance = \sqrt{\frac{S\varepsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$



5) Maximize tagging rate x dilution^2

Know your mistag rate from a Δm_d measure

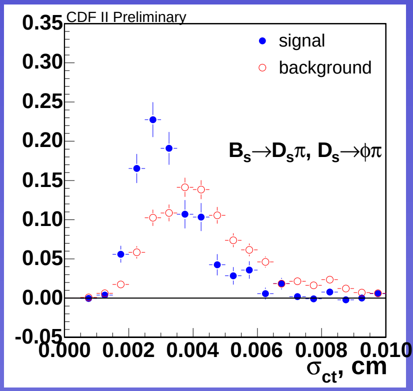
Need statistic!



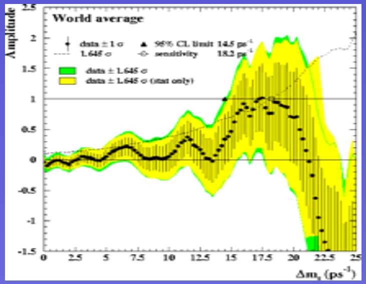
1) Trigger design to maximise Signal (S)→ highest BandWidth

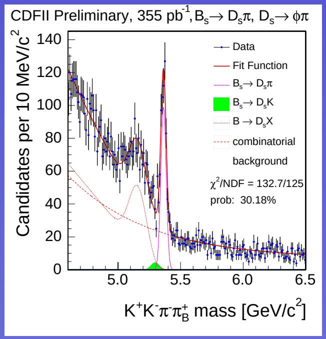
Fight for your Band Width (if in a general-purpose exp.)

Keep your trigger alive!

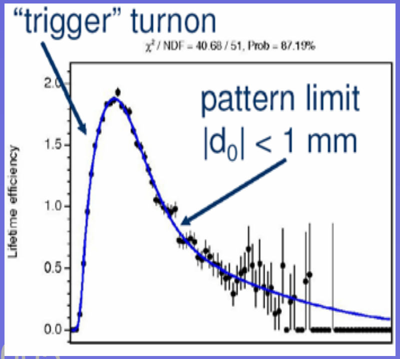


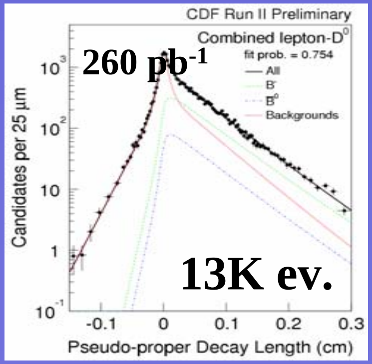
Amplitude scan





2) Good momentum (mass) and energy (!) resol. for max S/(S+B)





3) Measure τ_B on semileptonic & hadronic on multiple triggers

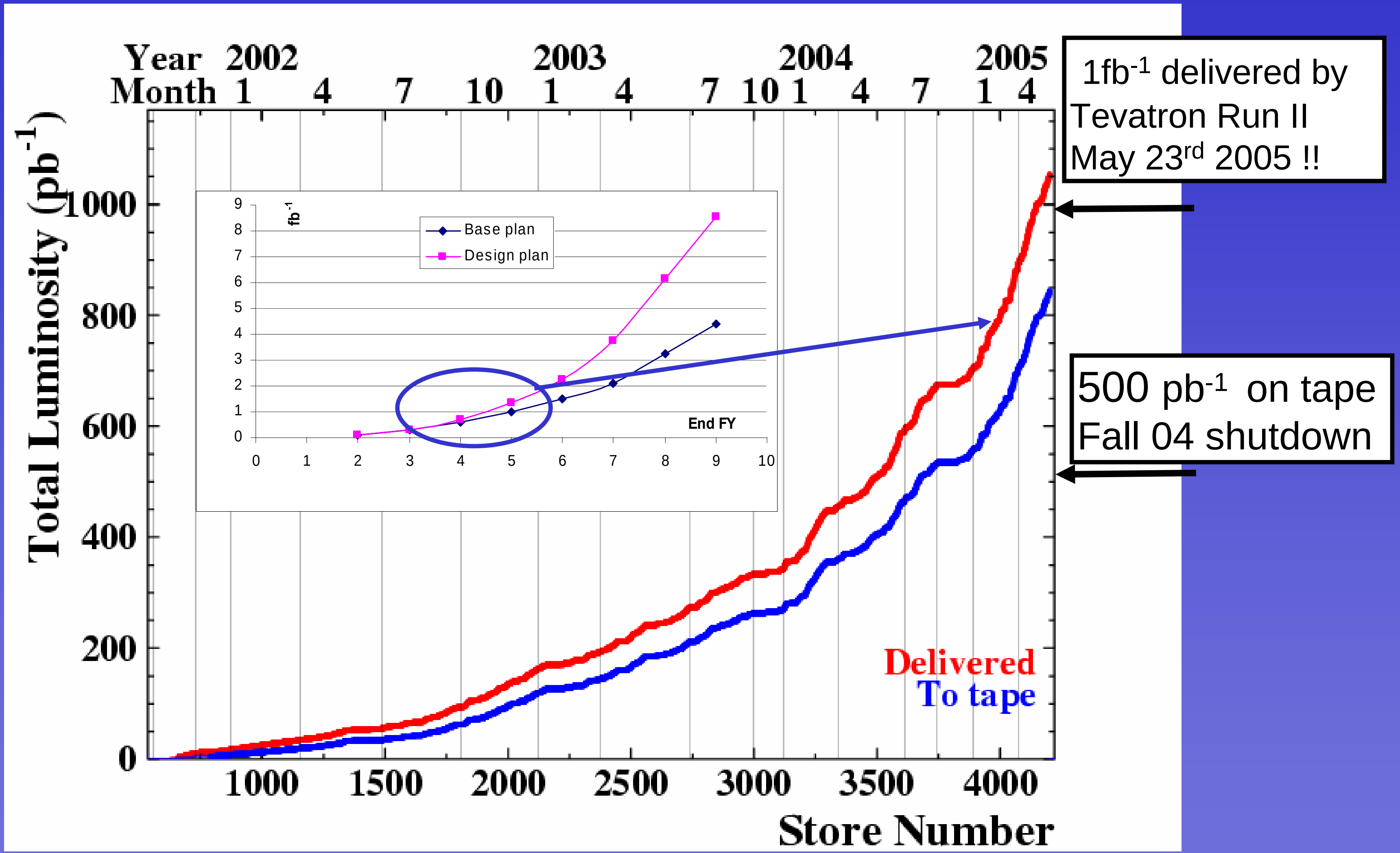
(with/without lifetime bias)

4) Improve σ_t :

- fully reconstructed !
- L00 close to beam pipe
- Primary vertex resolution.

Collecting data

Luminosity Delivered/Recorded

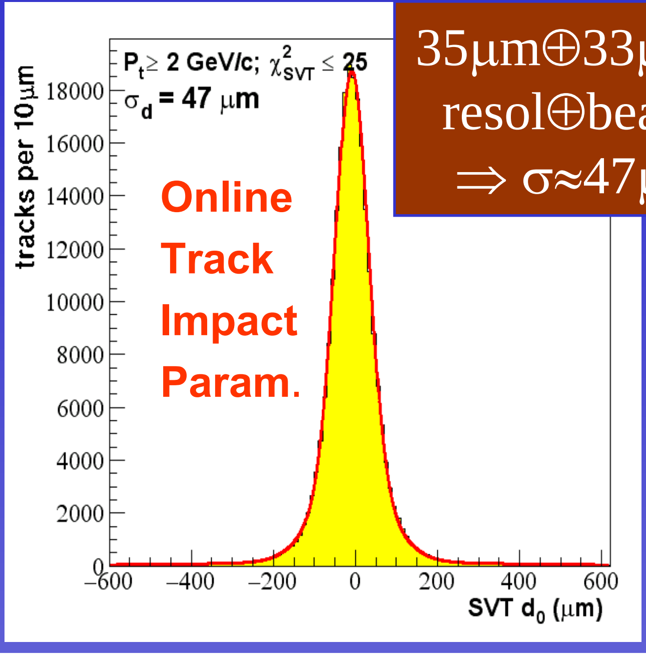


Present result based on ~360 pb^{-1}

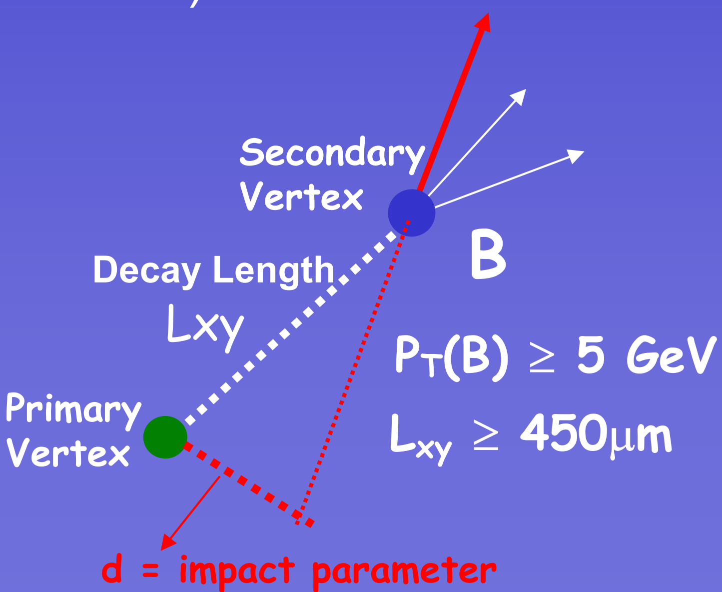
(100 pb^{-1} lost due to drift chamber ageing problem, now solved)

Silicon Vertex Tracker

- Triggering on displaced vertex at CDF using SVT main novelty in Run II, workhorse for CDF B-physics program. See at this conference:
  - Charmless decays (Donati)
  - SVT trigger (Dell'Orso)
- CDF way to get fully reconstructed decays useful for mixing (and other good stuff…)



35μm⊕33μm
resol⊕beam
⇒ σ≈47μm



Main Trigger requires:
- 2 opposite charge tracks,
- $P_t \geq 2$ GeV/c,
- impact parameter $|d_0| > 120\ \mu m$
- Scalar pt sum > 5.5 GeV/c
- Projected decay length $L_{xy} > 200\ \mu m$
- $2° < \Delta\phi < 90°$

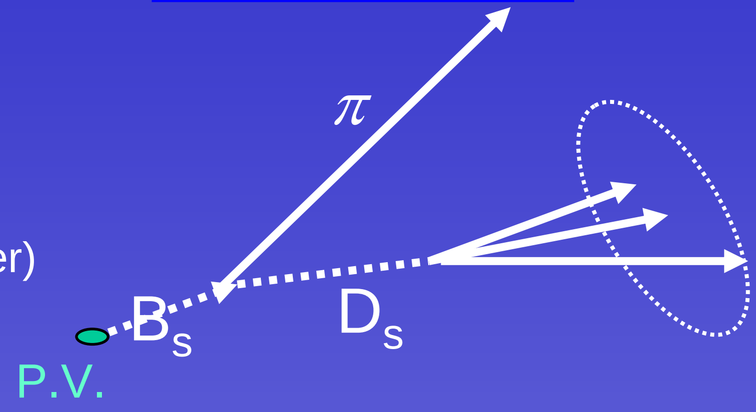
Add a dynamically prescaled LOWPT trigger with no opposite charge and no Pt sum to fill available bandwidth at low luminosity

Two different B_s signatures:

$$B_s^0 \rightarrow D_s^- \pi^+$$

Fully reconstructed HADRONIC modes:

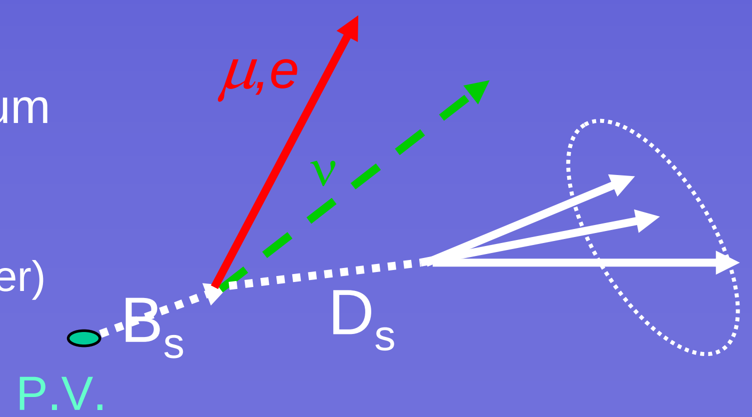
- Complete momentum reconstruction
- Good proper time resolution
- High Bs mass resolution → high S/B
- Selected by Two Track Trigger (SVT)
  - Two displaced tracks (w large SVT Impact parameter)
- LOW statistics (useful BR)
- Demanding on L1 B/W: >30 KHz @ 1E32cm^{-2}s^{-1}
  ~10 KHz @ 5E31cm^{-2}s^{-1}



$$B_s^0 \rightarrow D_s^- l^+ \nu_l X$$

Partially reconstructed SEMILEPTONIC modes:

- Missing momentum carried by the ν
- Visible proper time corrected from MC (K factor)
- Proper time resolution diluted by missing momentum
- Cannot reconstruct Bs mass → different S/B
- Selected by dedicated trigger (l+SVT):
  - One displaced tracks (w large SVT Impact parameter)
  - One Lepton μ,e (p_T >4 GeV/c)
- HIGH statistics and well behaved trigger



Hadronic B_s signals

$$B_s^0 \to D_s^- \pi^+ (D_s^- \to \phi \pi^-)$$

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

N_{B_s} = 526±33

S/B ~ 2

$\sigma_M \approx$ 15 MeV

"Satellites":

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

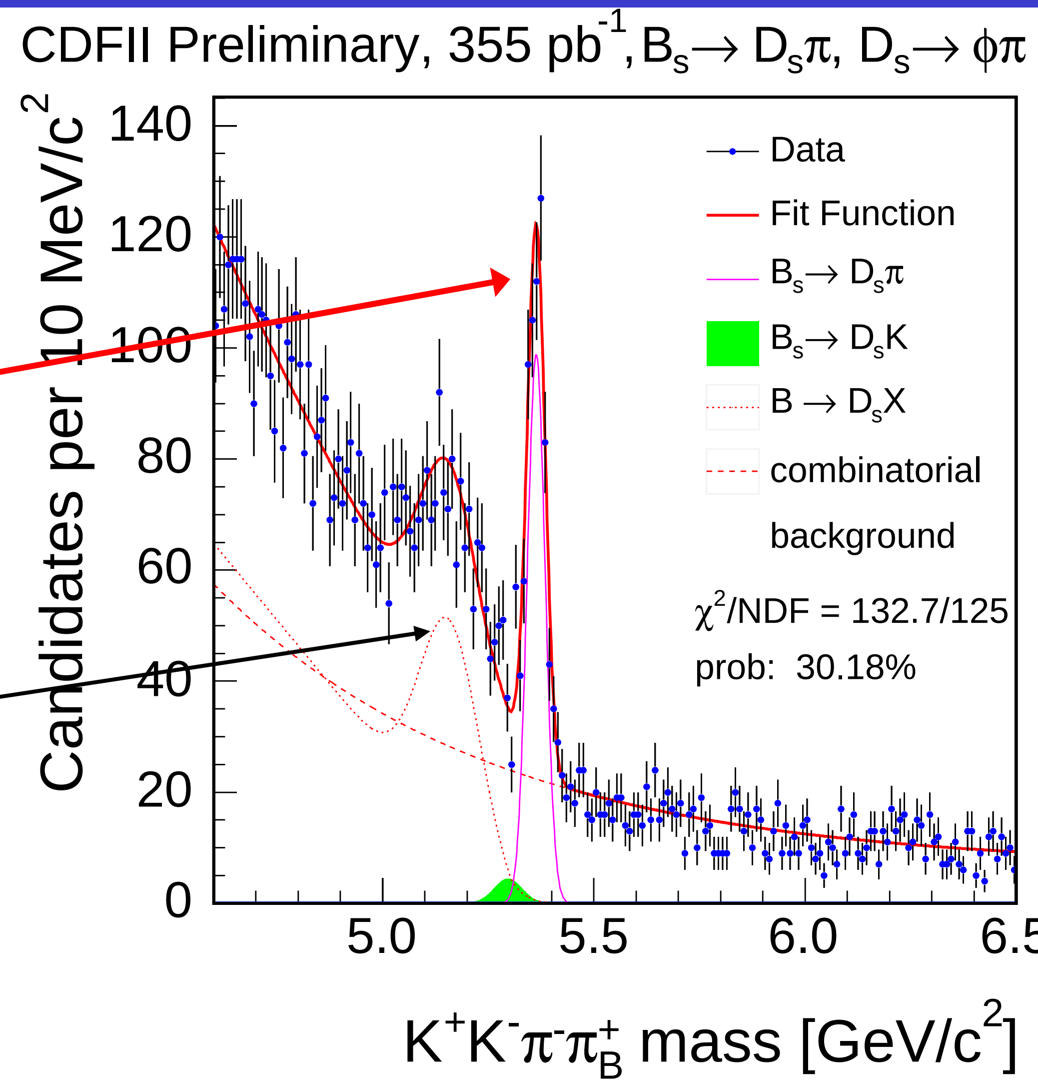
$$B_s^0 \to D_s^- \rho^+ (\rho^+ \to \pi^+ \pi^0)$$

(Not used in this analysis)

Other signals:

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

$$B_s^0 \to D_s^- \pi^+ (D_s^- \to \pi^- \pi^+ \pi^-)$$

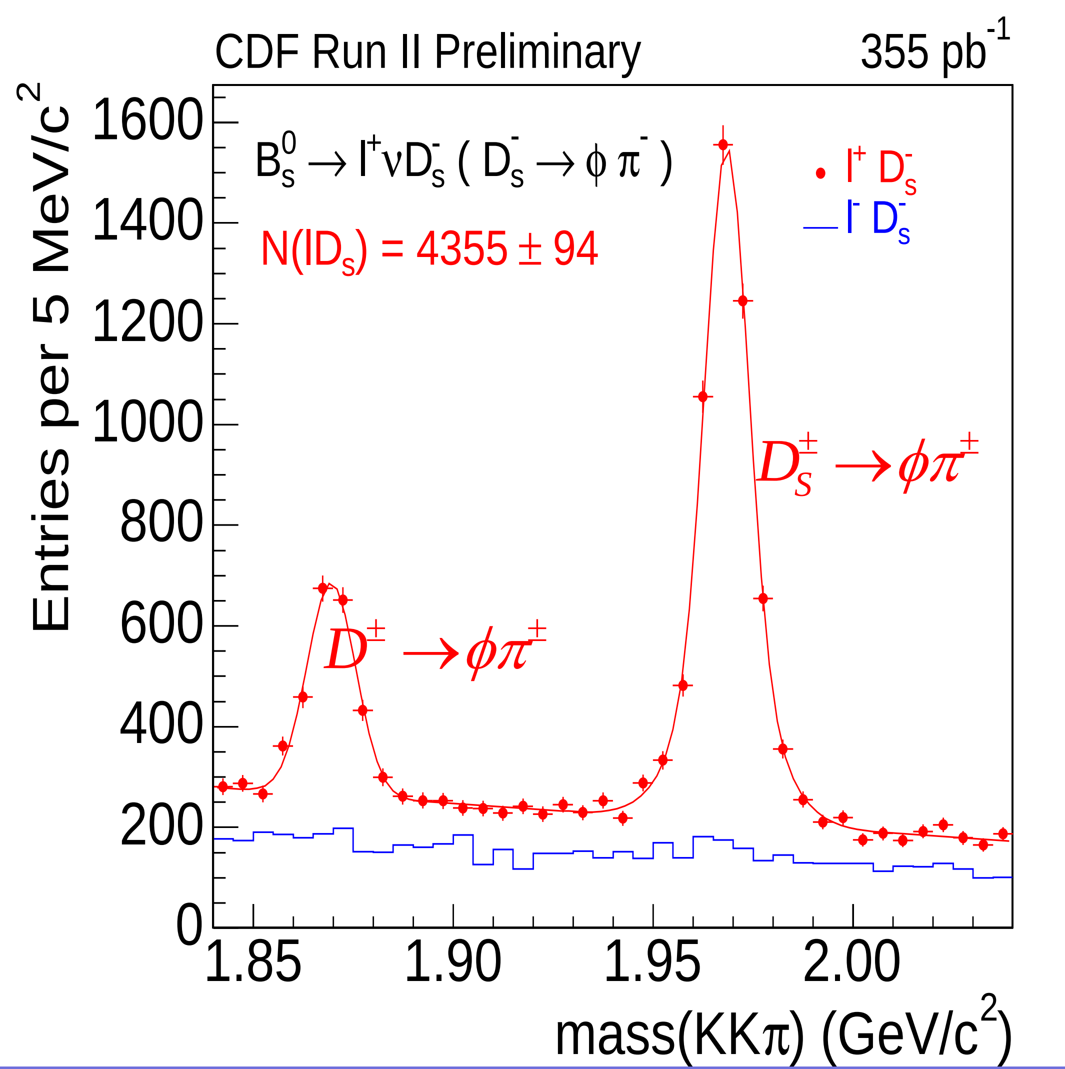


Semileptonic B_s Signals

$$B_s^0 \to D_s^- l^+ \nu X \,(D_s^- \to \phi\pi^-)$$

Other signals

- Missing P_T ➡ No B_s mass peak
- Use D_s mass signals
- Charge correlation between ℓ and D_s
  - $\ell^+ D_s^-$: "Right-sign" = signal
  - $\ell^- D_s^-$: "Wrong-sign" = background
- Right-sign peak is not pure signal
  - ~20% background:
    - » D_s + fake lepton from primary
    - » $B^0, B^+ \to D_s\, D\, X$ with $D \to \ell \nu X$
    - » c-$\bar{c}$ backgrounds



Signal Yields Summary

	(S/B)
$B_s \to D_s\pi$; $D_s \to \phi\pi$	526±33 (1.8)
$B_s \to D_s\pi$; $D_s \to K^*K$	254±21 (1.7)
$B_s \to D_s\pi$; $D_s \to \pi\pi\pi$	116±18 (1.0)
$B^+ \to D^0\pi^+$; $D^0 \to K\pi$	~6200
$B^0 \to D^{*+}\pi^-$; $D^{*+} \to D^0\pi^+$	~2800
$B^0 \to D^+\pi^-$; $D^+ \to K\pi\pi$	~5600

Hadronic B_s modes
~900 events

$O(10^4)$ B^0/B^+ calibration modes

	(S/B)
$B_s \to \ell D_s$; $D_s \to \phi\pi$	4355±94 (3.1)
$B_s \to \ell D_s$; $D_s \to K^*K$	1750±83 (0.4)
$B_s \to \ell D_s$; $D_s \to \pi\pi\pi$	1573±88 (0.3)
$B^+ \to \ell D^0$; $D^0 \to K\pi$	~100K
$B^0 \to \ell D^{*+}$; $D^{*+} \to D^0\pi^+$	~25K
$B^0 \to \ell D^+$; $D^+ \to K\pi\pi$	~52K

Semileptonic B_s modes
~7700 events

$O(10^5)$ B0/B+ calibration modes

Measuring ct

Decay Time Bias

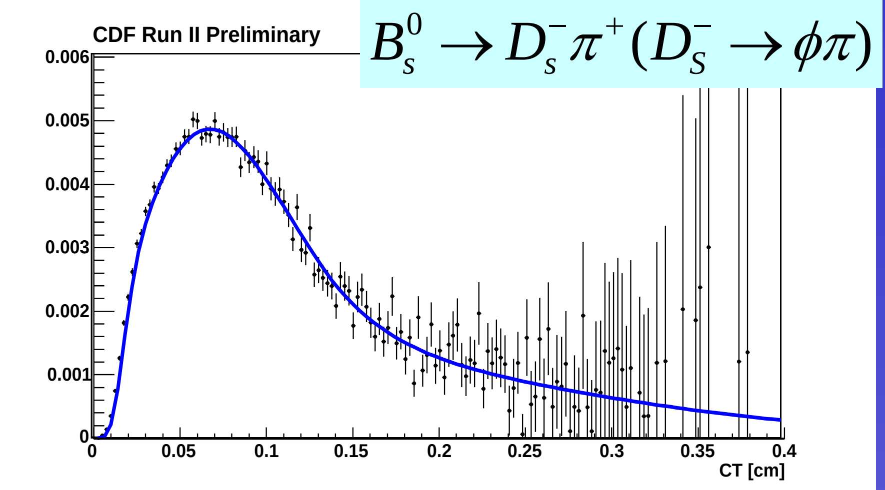
Extract proper time at decay from B flight distance in the transverse plane:

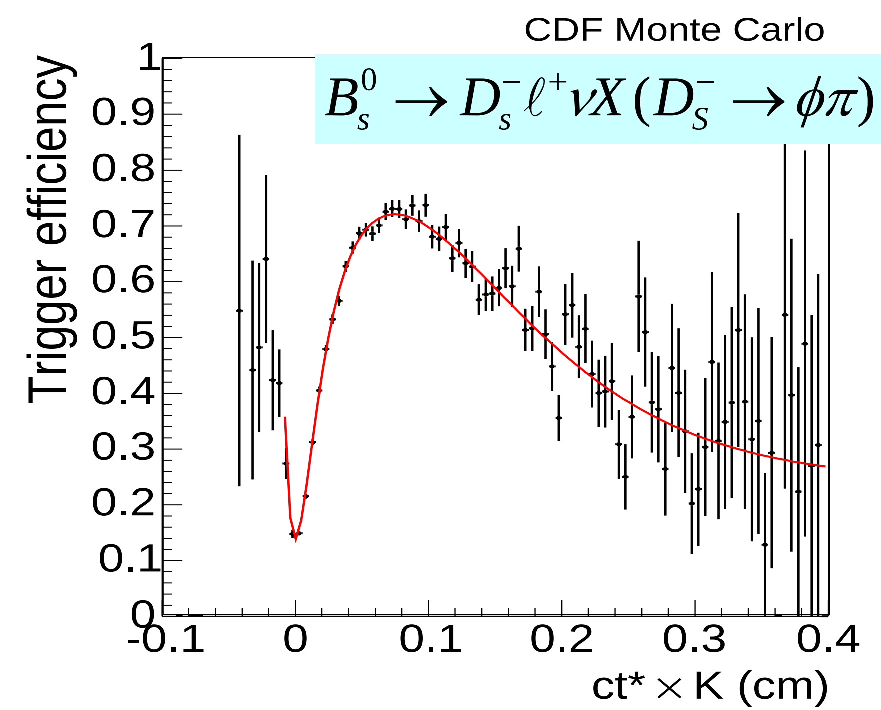
$$ct = \frac{L}{\beta\gamma} = L_{xy} \times \frac{m(B)}{p_T(B)}$$

Two complications:

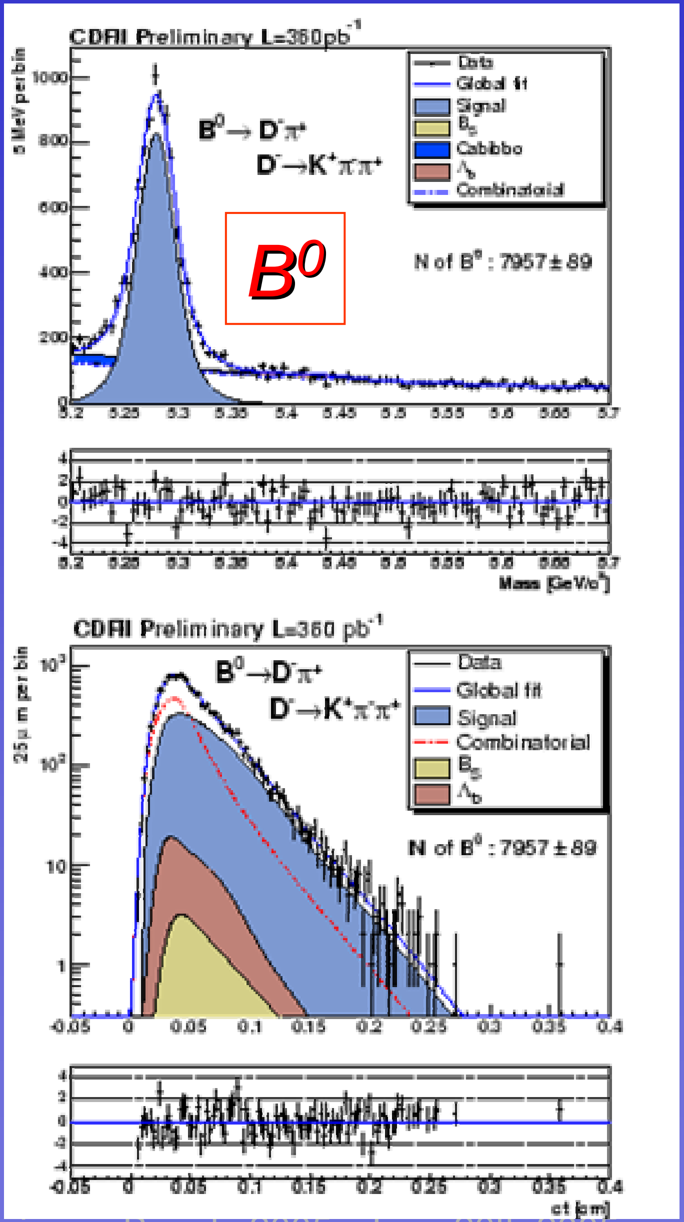
1. Trigger bias on L_{xy}
2. Correct for missing ν in semileptonic

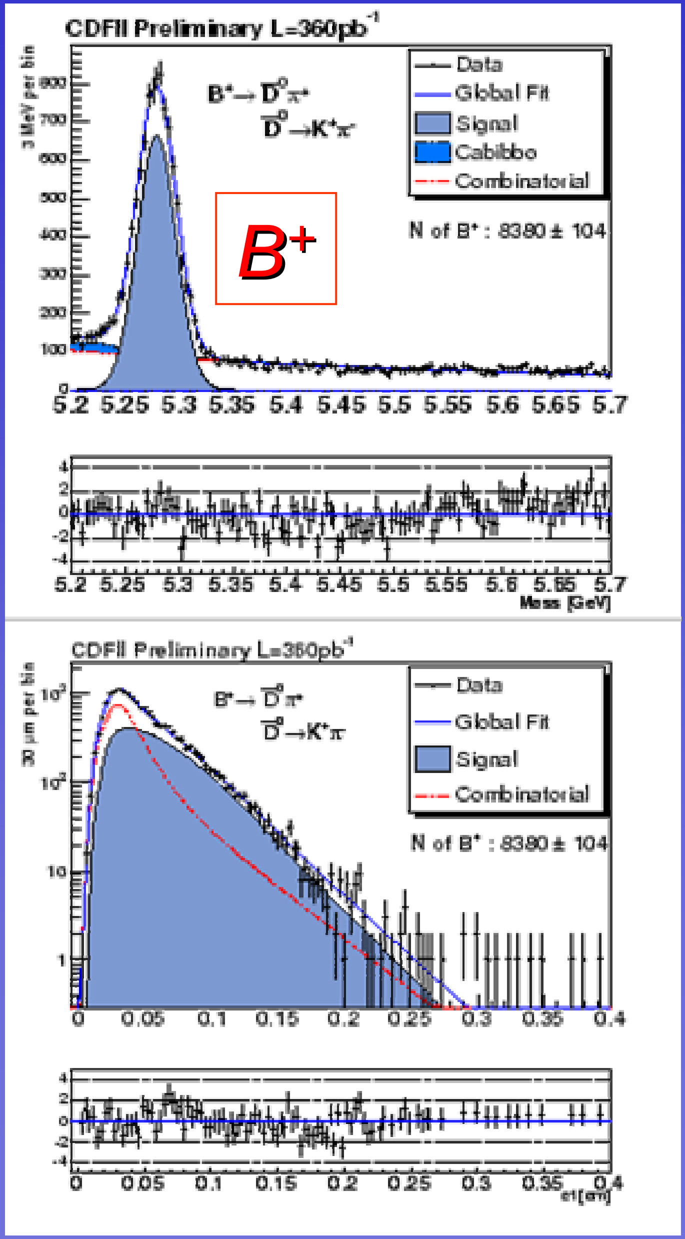
- Trigger and reconstruction requirements affect L_{xy}
  - Trigger (impact parameter) cuts at low ct
  - SVT acceptance at high ct
- "ct" efficiency from Monte-Carlo:
  - B production/decay model
  - detailed Trigger/Detector simulation
- Test with high-statistic B^0/B^+ samples



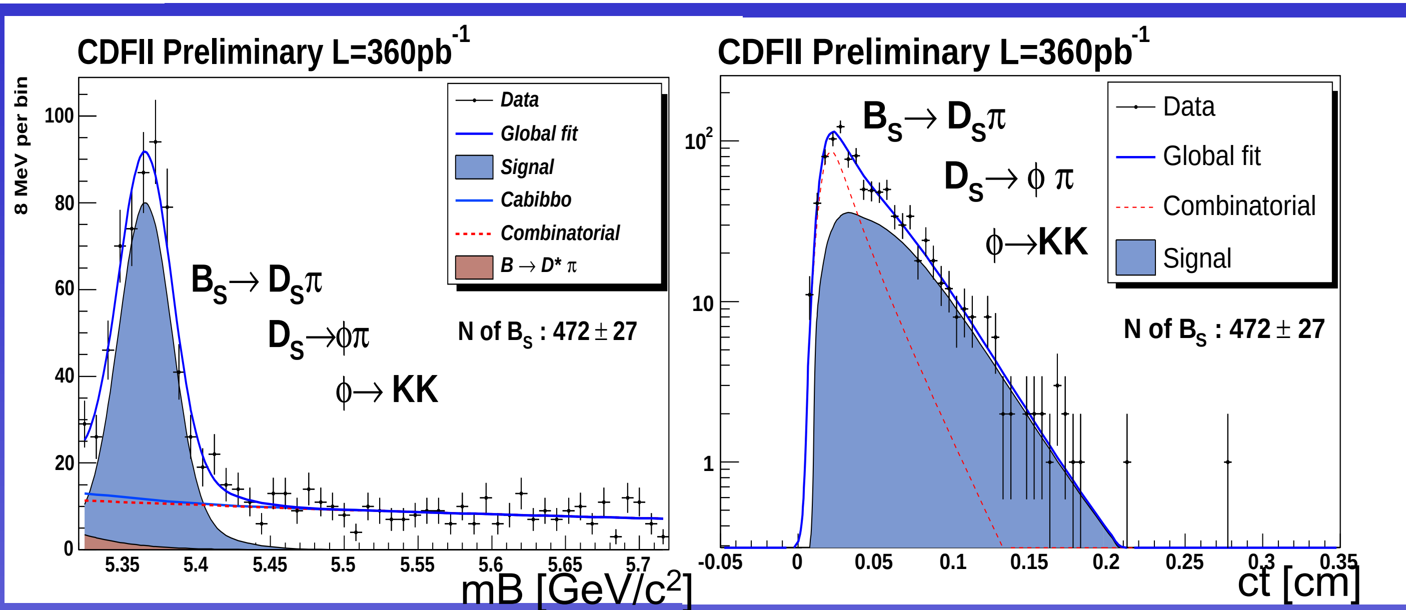


B^0 and B^+ hadronic modes $c\tau$





Hadronic Modes Lifetime



± (stat) ± (syst)

$\tau(B^+) = \mathbf{1.661 \pm 0.027 \pm 0.013}$ **ps**

$\tau(B^0) = \mathbf{1.511 \pm 0.023 \pm 0.013}$ **ps**

$\tau(B_s) = \mathbf{1.598 \pm 0.097 \pm 0.017}$**ps**

HFAG 04 average

$\tau(B^+) = \mathbf{1.653 \pm 0.014}$ **ps**

$\tau(B^0) = \mathbf{1.534 \pm 0.013}$ **ps**

$\tau(B_s) = \mathbf{1.469 \pm 0.059}$ **ps**

Systematic summary [%]

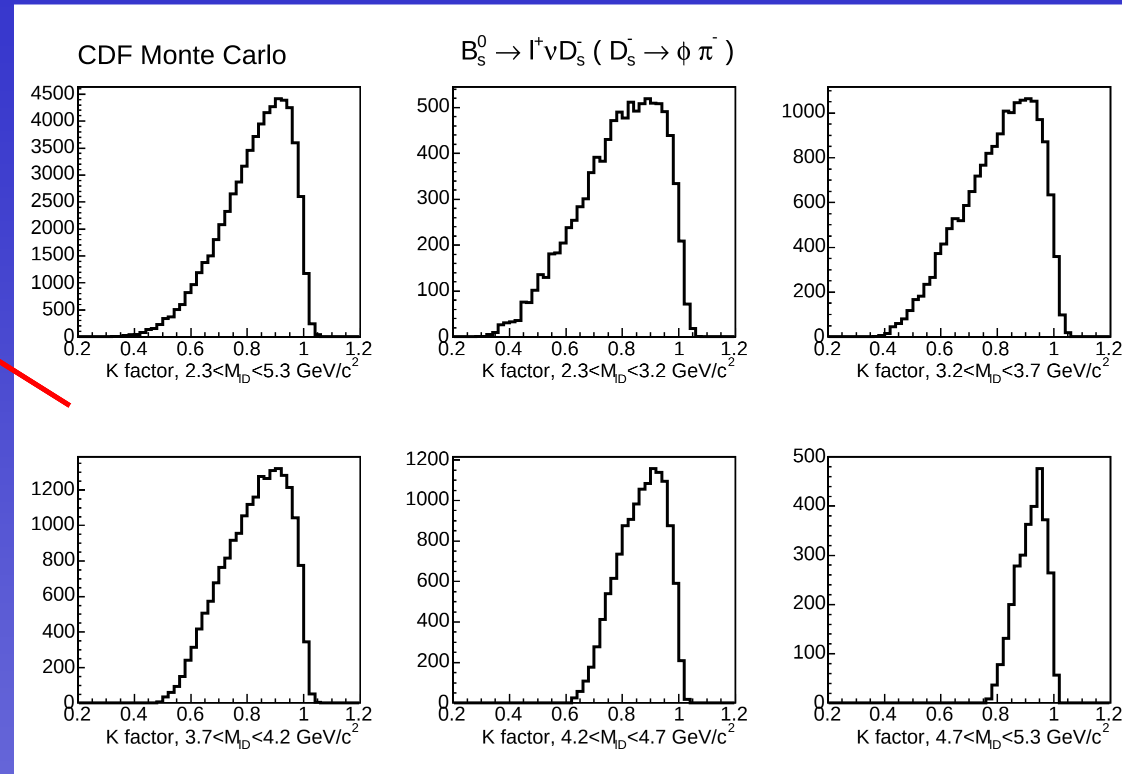
Effect	Variation(μm)	Variation(μm)
	B^0	B_s
MC input $c\tau$	negligible	negligible
p_T reweight	1.9	1.9
Scale Factor	negligible	negligible
Bkg ct description	1.1	1.1
Bkg fraction	2.0	2.0
I.P. correlation	1.0	1.0
Eff. parameterization	1.5	1.5
L_{xy} significance	negligible	2
$\Delta\Gamma_s$	-	1.0
Alignm. + others	2.4	2.4
Total	4.2	4.7

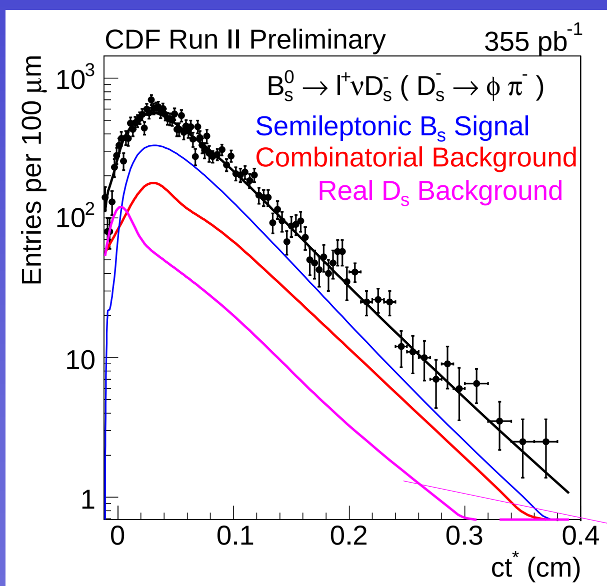
SVT bias
syst. small

Semileptonic B_s Modes Lifetime

Introduce K factor $=p(\ell D_s)/p(B)$ to account for missing ν

$$ct^* = L_{xy} \times \frac{m(B)}{p_T(\ell D_s)} \otimes K$$





$\tau = 1.521 \pm 0.040$ ps

Real D_s backgrounds: prompt and physics

Combined ℓ-D_s lifetime result: 1.477 ± 0.032 **ps** *stat. err .only (analysis ongoing)*

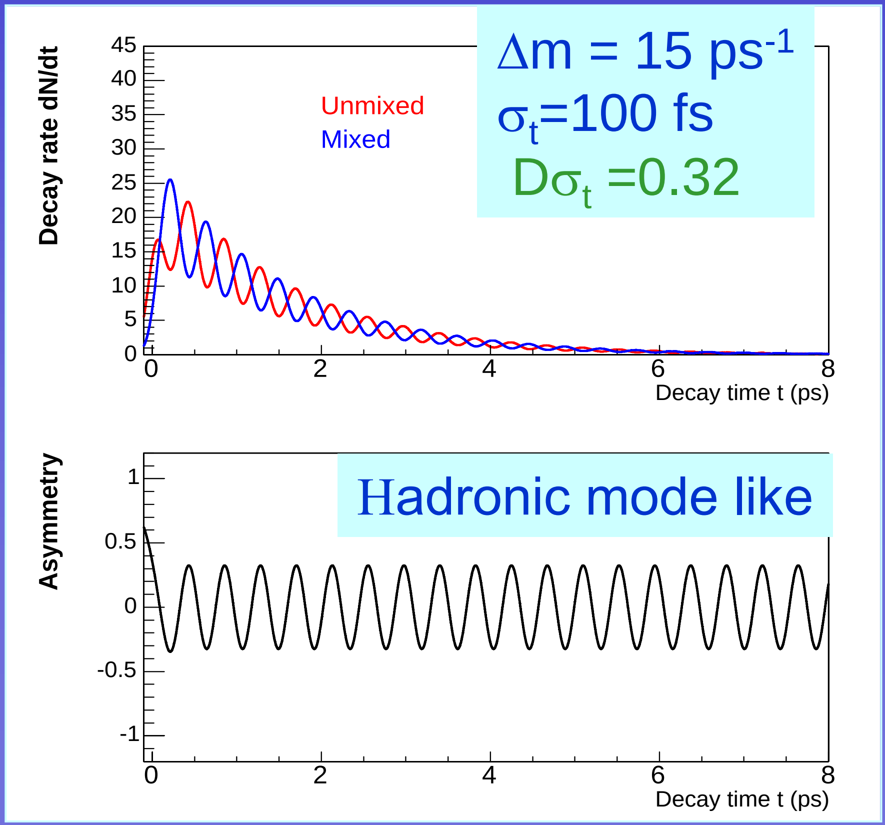
HFAG '05 flavour specific: 1.472 ± 0.045 ps (DØ '05 $D_s l$: 1.420±0.043±0.057 ps)

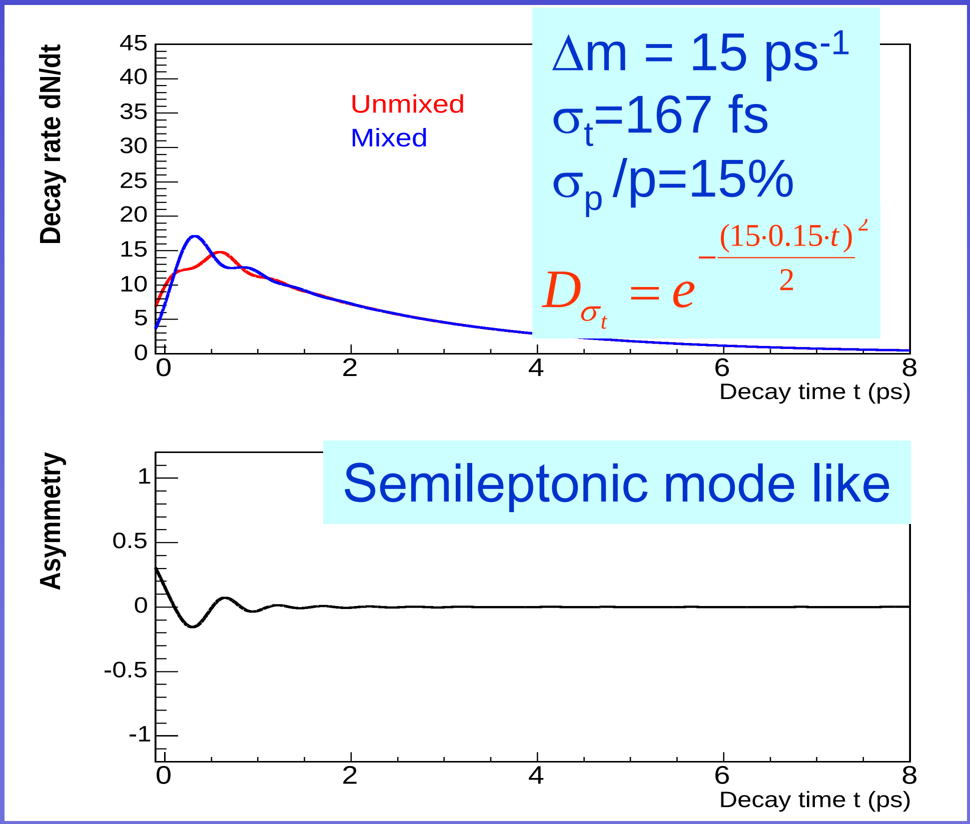
Effect of proper time resolution

- The amplitude of mixing asymmetry is diluted by a factor $D_{\sigma_t} = e^{-\frac{(\Delta m \cdot \sigma_t)^2}{2}}$

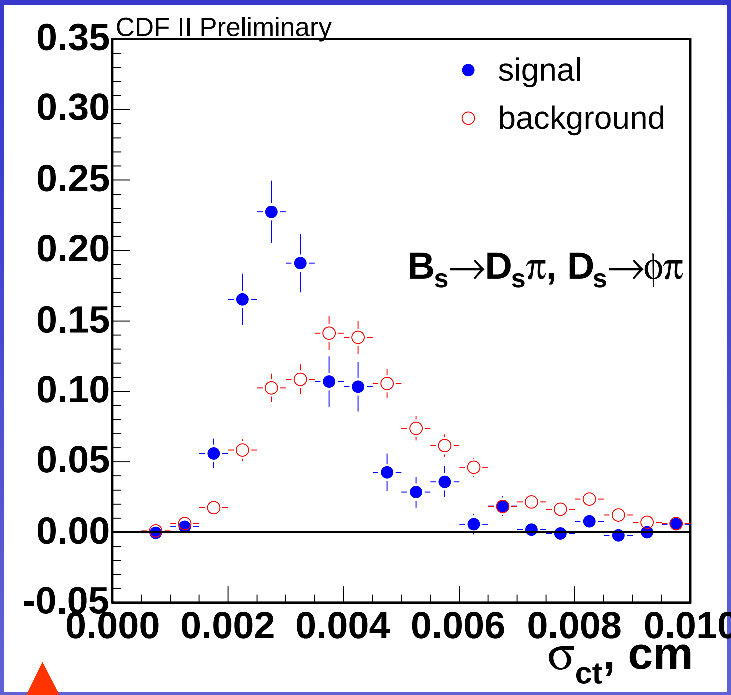
$$\sigma_{ct} = \sqrt{\left(\sigma_{ct}^{0}\right)^2 + \left(ct \times \frac{\sigma_p}{p}\right)^2}$$

Vertex resolution (constant) | Momentum resolution (proportional to ct)

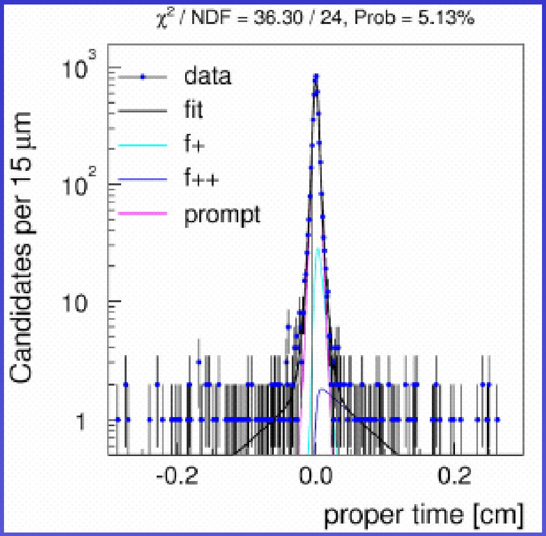




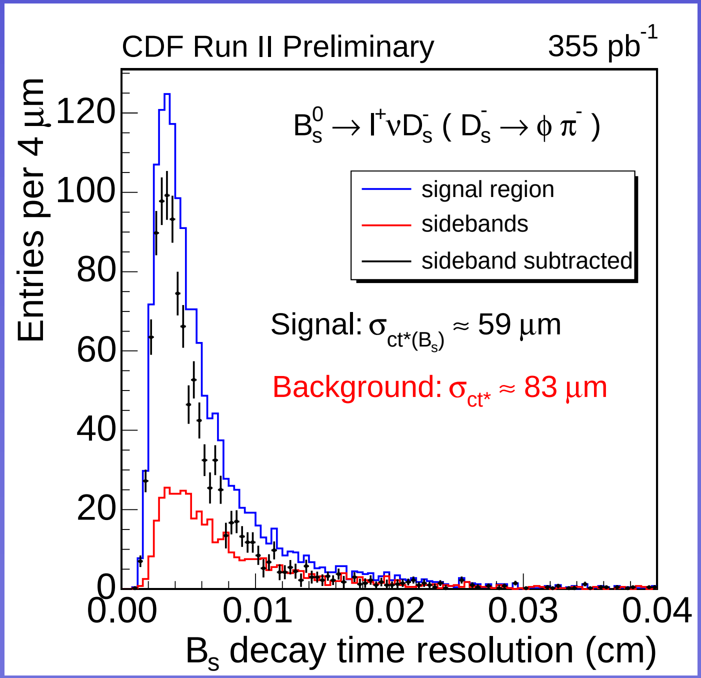
B_s decay time resolution



Huge prompt (90%) D_s + track sample to correct σ_{ct} error calculation and parameterize as a function of several variables.



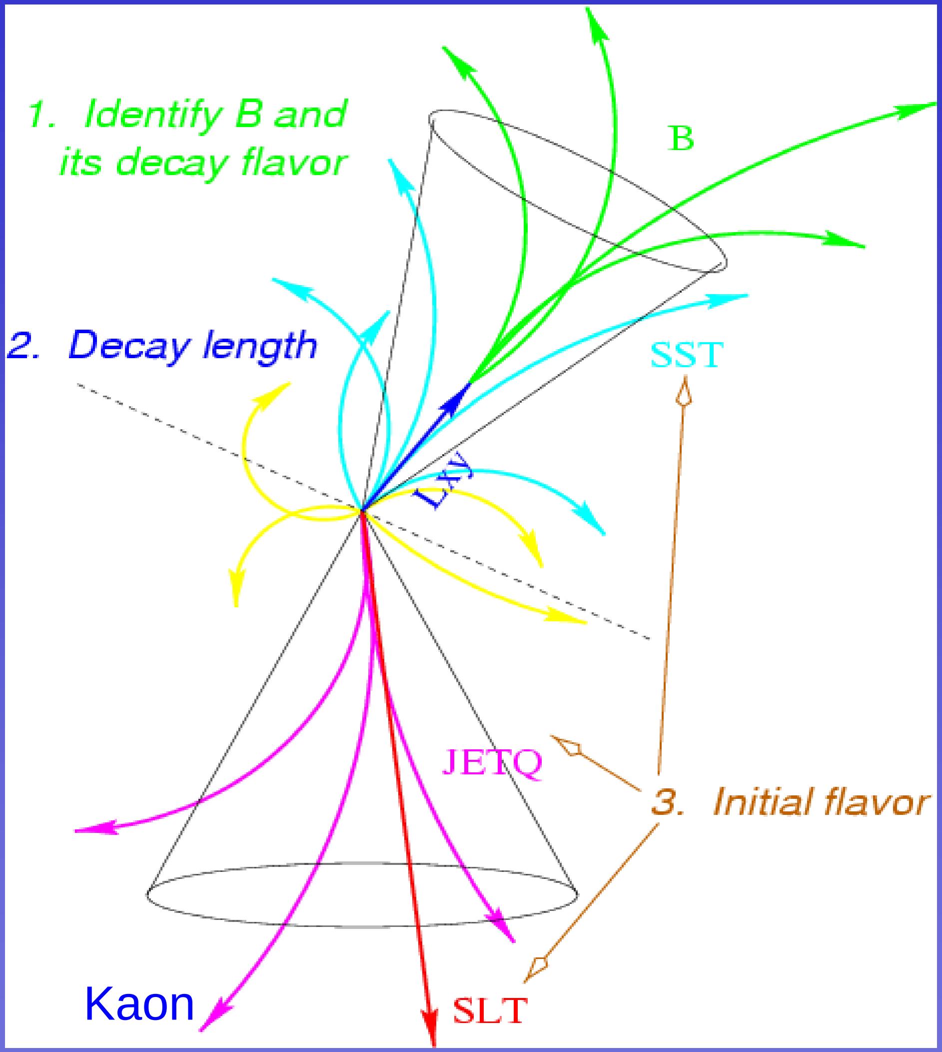
- Hadronic:
  - $<\sigma_{ct}^0>$: ~ 30 μm (100 fs)
  - $\sigma p/p < 1\%$
- Semileptonic
  - $<\sigma_{ct}^0>$: ~ 50 μm (167 fs)
  - $\sigma p/p$ ~ 15% (K factor due to missing neutrino)



Flavour Tagging

Flavor Tagging

- Same side tagging
  - Use fragmentation track
  - B^0, B^+, and B_s are different
  - Kaon around B_s: PID is important (more at the end of the talk)



- Opposite side tagging (5 algo)
  - Use the other B in the event
  - Semileptonic decay ($b \rightarrow l^-$)
    - (1) Muon, (2) Electron
  - Use jet charge (Q_b = -1/3)
    - (3) Jet has 2ndary vertex
    - (4) Jet contains displaced track
    - (5) Highest momentum Jet

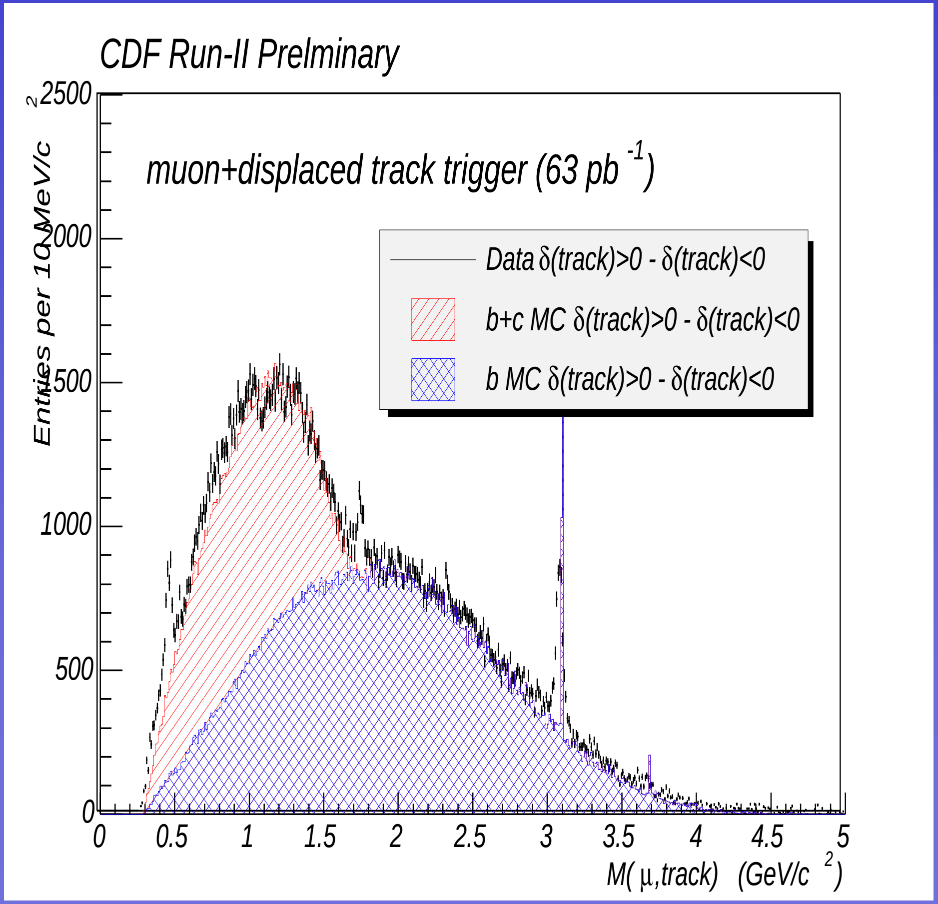
Used only Opposite Side Tags so far for B_s

Calibration Sample for Taggers

- Need high stat. sample to develop and calibrate tagging algorithm:

- Use inclusive semileptonic decays from the lepton+track trigger (>10^6 events)
  - –Lepton charge gives "true" B flavour
  - –Tag the other b

- High purity reached after lepton+track mass cut applied



- Statistical Power of a tag: εD^2
  - Tagging efficiency (ε)
  - Tagging dilution (D = 1-2w)
    - w = mistag rate

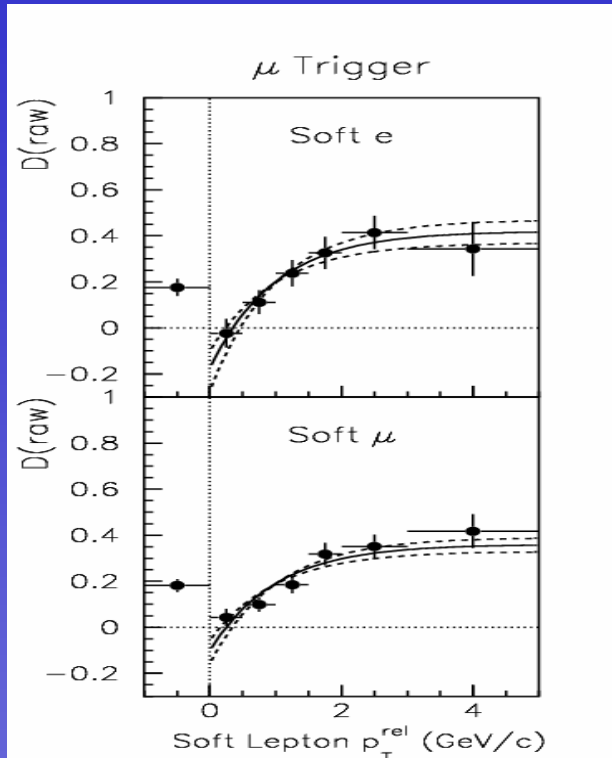
- Parameterize dilution as a function of relevant variables and wheight events with their event-by-event dilution

- Dividing events into different classes based on tagging power improves combined εD^2

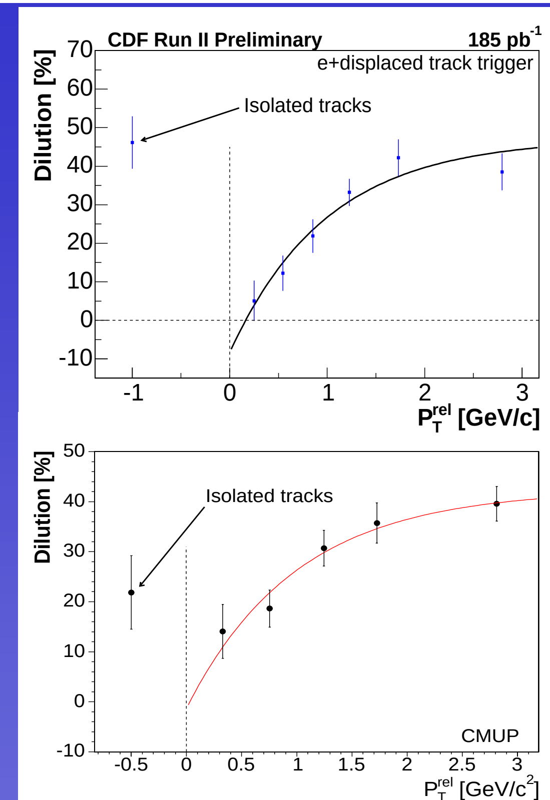
- Calibration of the tagger performance requires high statistics!

Flavor tagging – Soft Leptons

Run I



Run II



Likelihood based electron and muon ID

Using combination of calorimeter,muon detector,dE/dx info

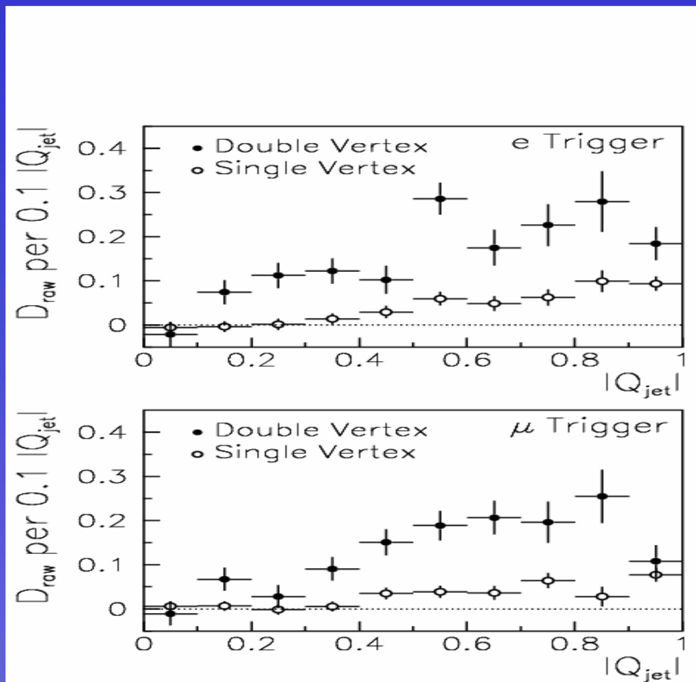
Similar performance as in Run I ($\varepsilon D^2=0.9\pm0.1$ %)

D_{max}~0.4 → 30% mistag rate

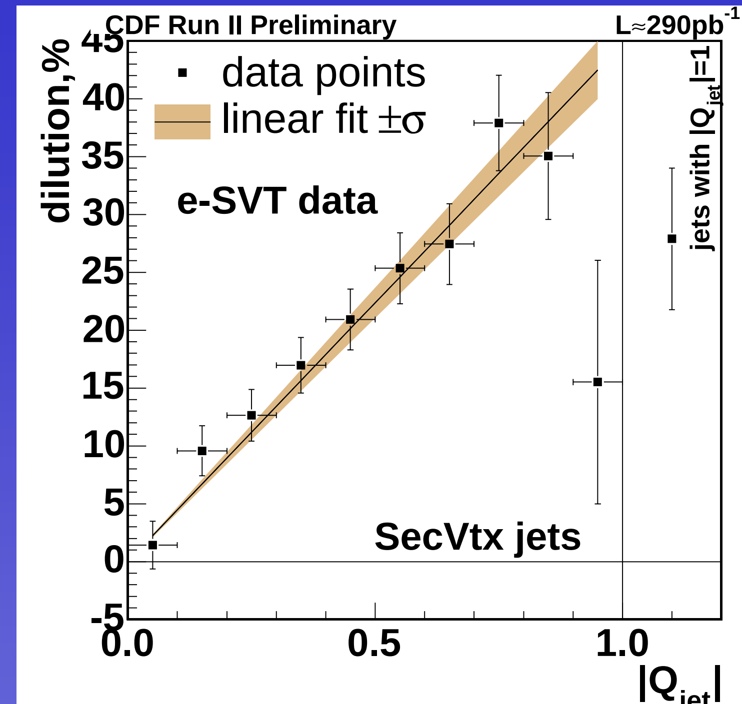
Tag type	εD^2 (%)
Muon	(0.70±0.04)%
Electron	(0.37±0.03)%
2ndary vtx	(0.36±0.02)%
Displaced track	(0.36±0.03)%
Highest p jet	(0.15±0.01)%
Total (exclusive)	~1.6%

Flavor tagging – Jet Charge

Run I



Run II



Cone based jet algorithm: compute Jet Charge of

- Secondary Vertex tagged jets
- Jet Probability tagged jet
- Highest P jet

Similar performance as in Run I (εD^2=0.8±0.1 %)

D_{max}~0.4 → 30% mistag rate

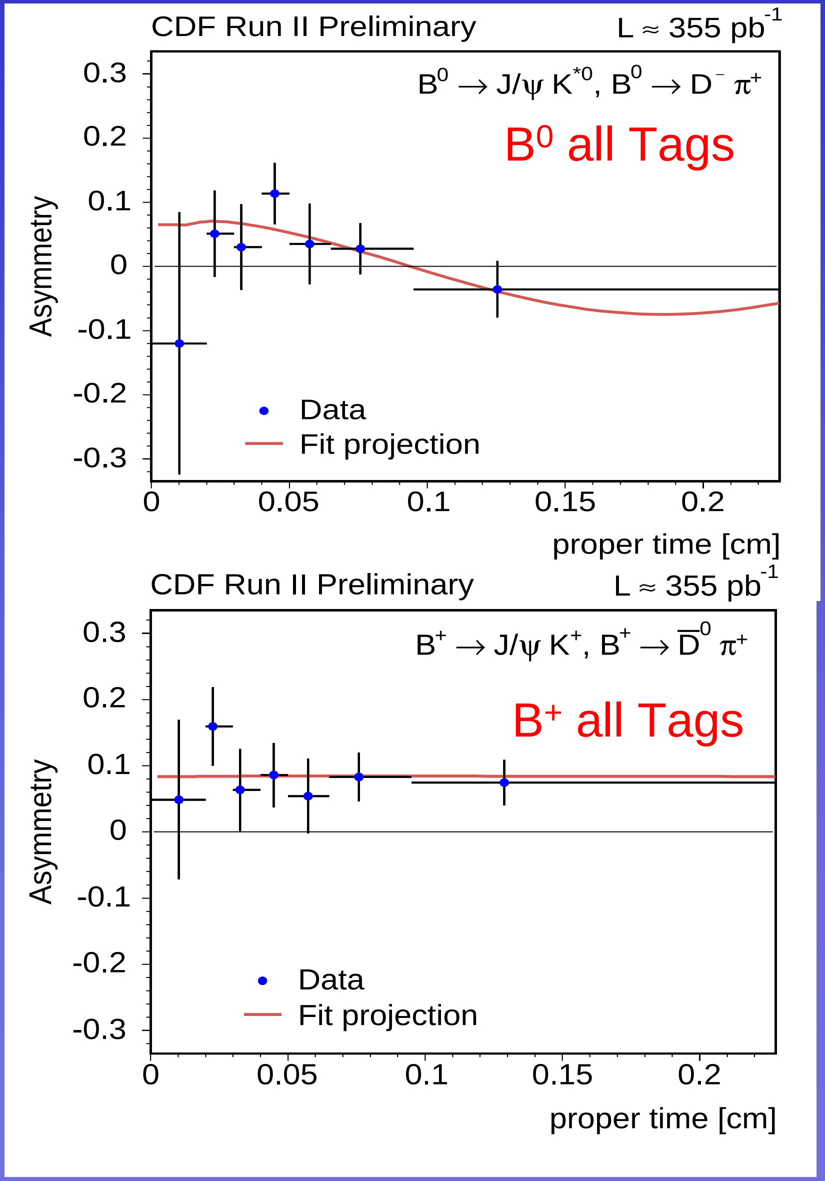
Tag type	εD^2 (%)
Muon	(0.70±0.04)%
Electron	(0.37±0.03)%
2ndary vtx	(0.36±0.02)%
Displaced track	(0.36±0.03)%
Highest p jet	(0.15±0.01)%
Total (exclusive)	~1.6%

B^0 mixing and dilution scaling

- Validation of the flavor tag calibration using B^0 and B^+ sample
  - $B^0 \rightarrow D\pi$, $B^+ \rightarrow D^0\pi$
  - $B^0 \rightarrow J/\psi K^{*0}$, $B^+ \rightarrow J/\psi K$

$$B^0 : e^{-t/\tau}\left(1 \pm S \cdot D \cdot \cos(\Delta m_d t)\right)$$

$$B^+ : e^{-t/\tau}\left(1 \pm S \cdot D\right)$$



- Fit the "Dilution scale factor" S
  - =1 if the tag calibration is correct.
  - 5 scale factors for 5 tag types
- Effective Dilution depend on detail of the samples (e.g. P_t spectra)

→ *Scale factors are then used for B_s mixing analysis for hadronic channels*

→ *Same thing for semileptonic decays*

B^0 mixing results

Dilution scale factor

	HADRONIC	SEMILEPTONIC
Δm_d	(0.503±0.063±0.015) ps^{-1}	(0.498±0.028±0.015) ps^{-1}
Total εD^2	(1.12±0.23)%	(1.43±0.09)%
Muon	0.83±0.10±0.03	0.93±0.04±0.03
Electron	0.79±0.14±0.04	0.98±0.06±0.03
Vertex	0.78±0.19±0.05	0.97±0.06±0.04
Track	0.76±0.21±0.03	0.90±0.08±0.05
Jets	1.35±0.26±0.02	1.08±0.09±0.09

- Δm_d consistent with WA: 0.510±0.005 ps^{-1}
- Total εD^2: 1.1—1.4%
- All dilution scale factors consistent with 1
  - Hadronic: 15~25% uncertainty
  - Semileptonic: 5~15% uncertainty

Δm_s scan

Amplitude Scan for $B^0_{d(s)}$

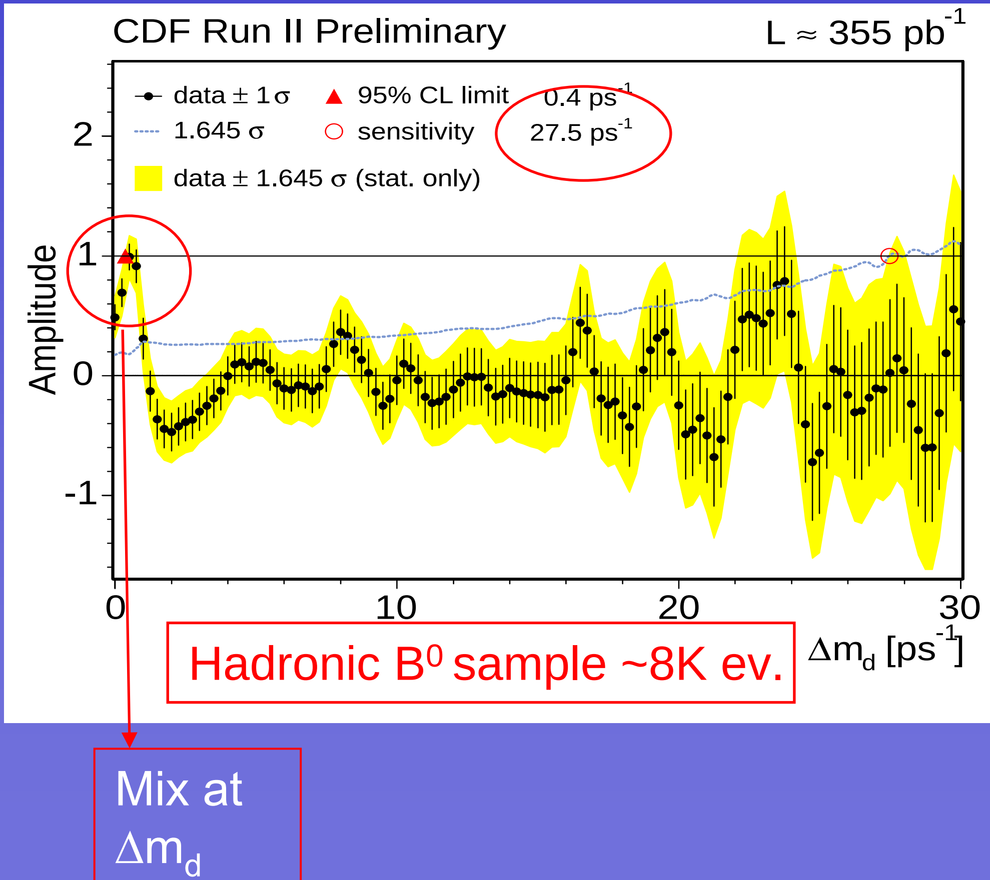
- Introduce "Amplitude" in Likelihood

$$L^t_{sig} = \frac{1}{\tau} e^{-t/\tau} \left(1 \pm A \cdot D \cdot cos(\Delta m \cdot t)\right)$$

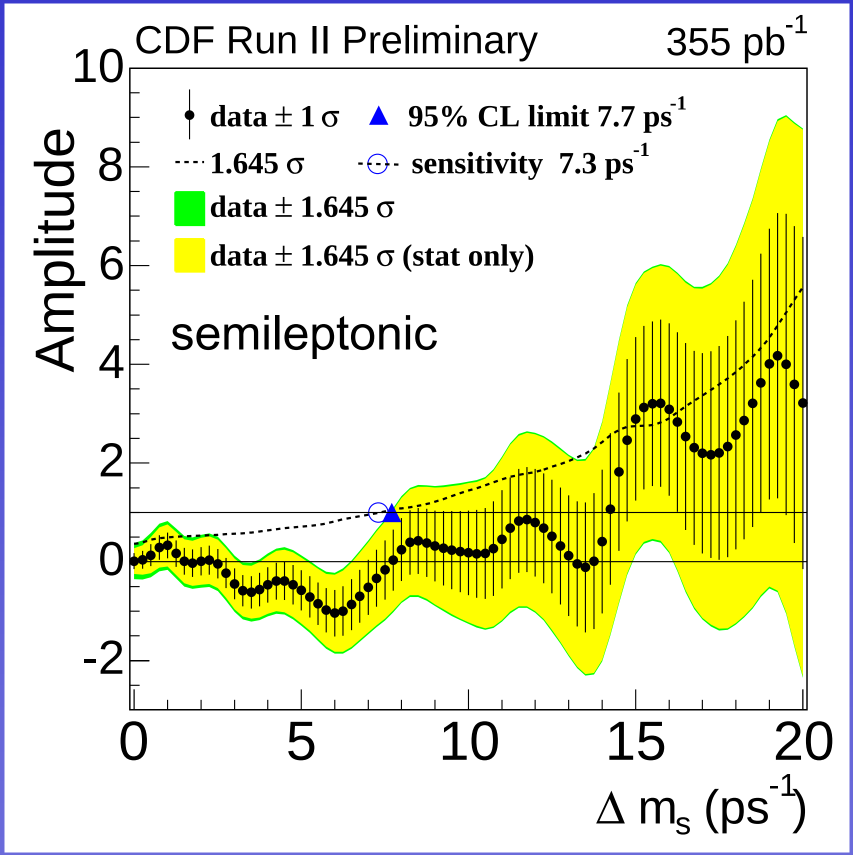
HFAG 04

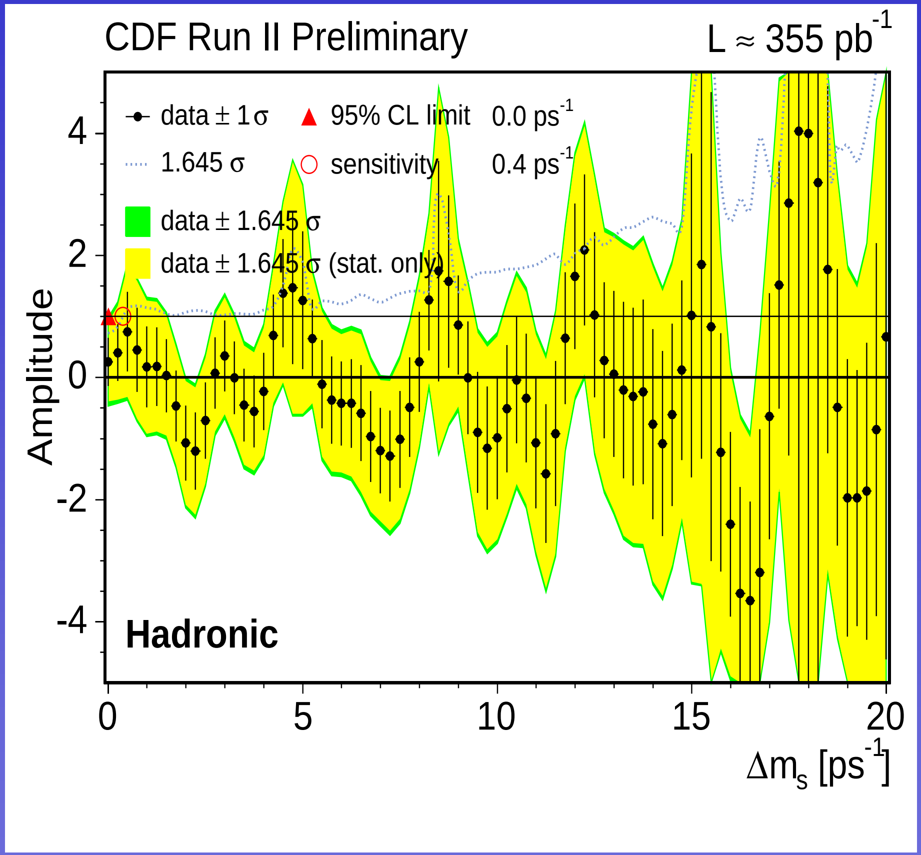
- 95% CL limit is : $\Delta m_s > 14.5\ ps^{-1}$
- Sensitivity: 18.2 ps^{-1}

- Amplitude scan
  - Fit the amplitude for fixed Δm
    - Amplitude: A, uncertainty: σ_A
  - Repeat the fit for different Δm
- Amplitude will be consistent with:
  - 1 if mixing detected at the frequency Δm
  - 0 if there is no mixing
- Example for B^0 Hadronic sample
  - Amplitude = 1 at Δm = 0.5 ps^{-1}
  - Amplitude = 0 at Δm >> 0.5 ps^{-1}



Amplitude Scan result



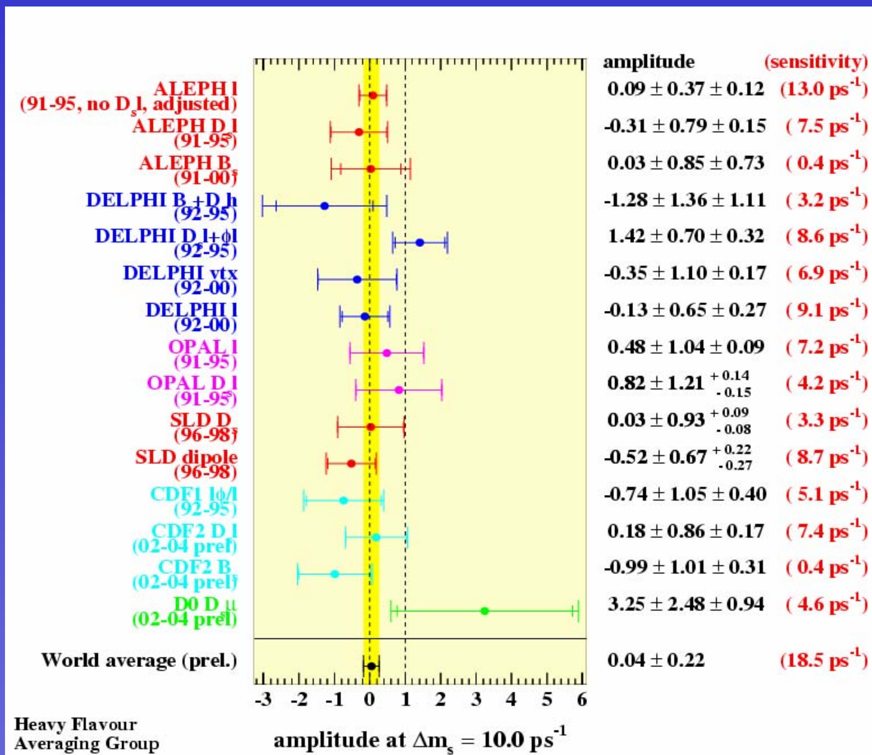


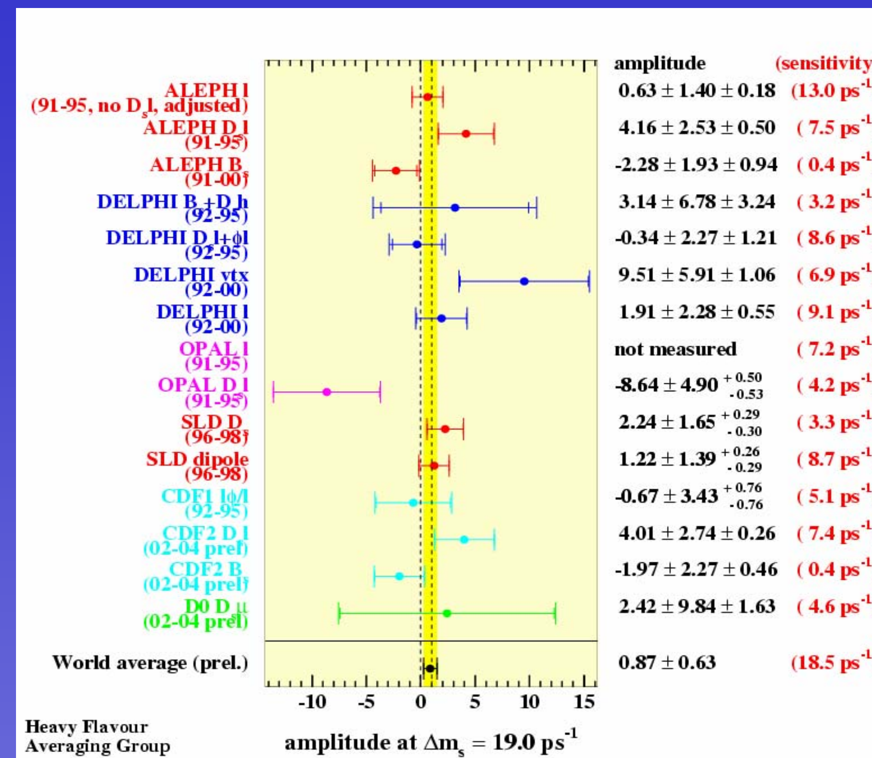
Hadronic has no sensitivity (yet) but is better behaved at high Δms

Systematic errors **are negligible** with respect to statistical in both cases

details

CDF/World Comparison





CDF2 B (hadronic) 9th best @ Δm_s=10ps^{-1} → 5th best @ Δm_s=19ps^{-1}

[180% → 60 % worse sensitivity than best experiment]

CDF2 Dl (semil.) 7th best @ Δm_s=10ps^{-1} → 8th best @ Δm_s=19ps^{-1}

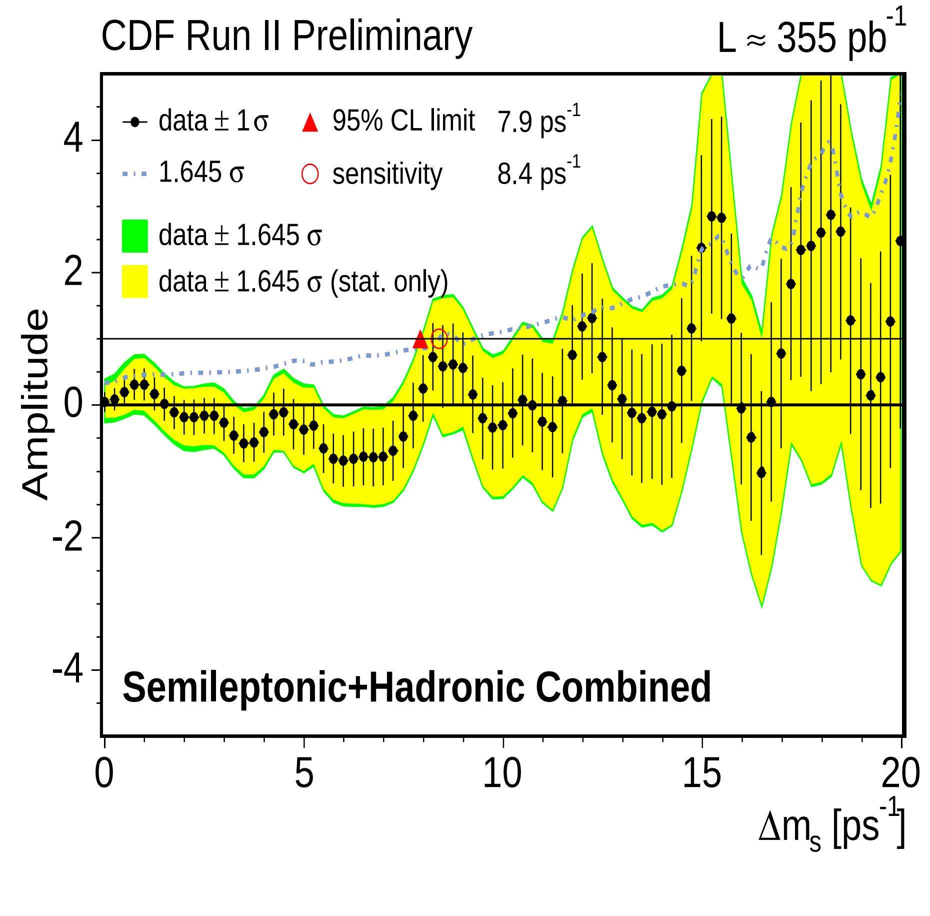
[130% → 95 % worse sensitivity than best experiment]

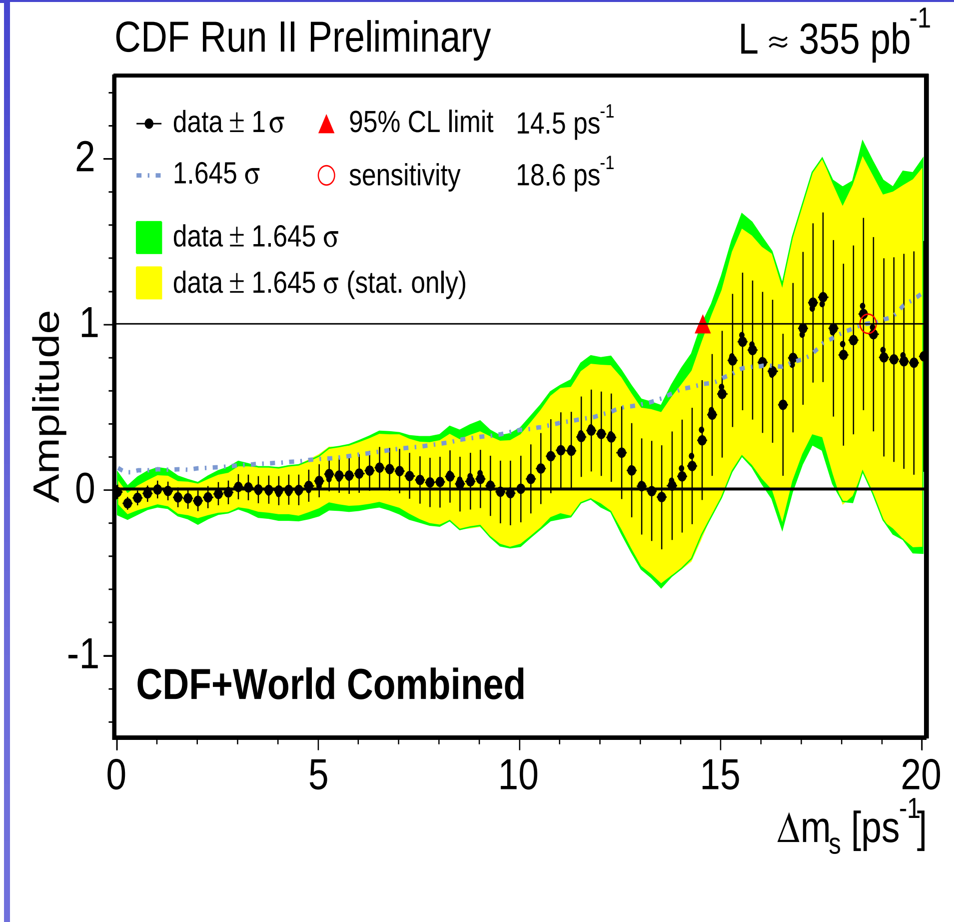
Stat. only!

CDF+World Combined Result

- <u>CDFII combined result</u>
- Sensitivity: 8.4 ps^{-1}
- Limit: Δm_s > **7.9 ps^{-1}** @ 95% CL

- <u>World Average + CDF Run II</u>
  - Sensitivity: 18.6 ps^{-1}
  - Limit >14.5 ps^{-1} @ 95% CL

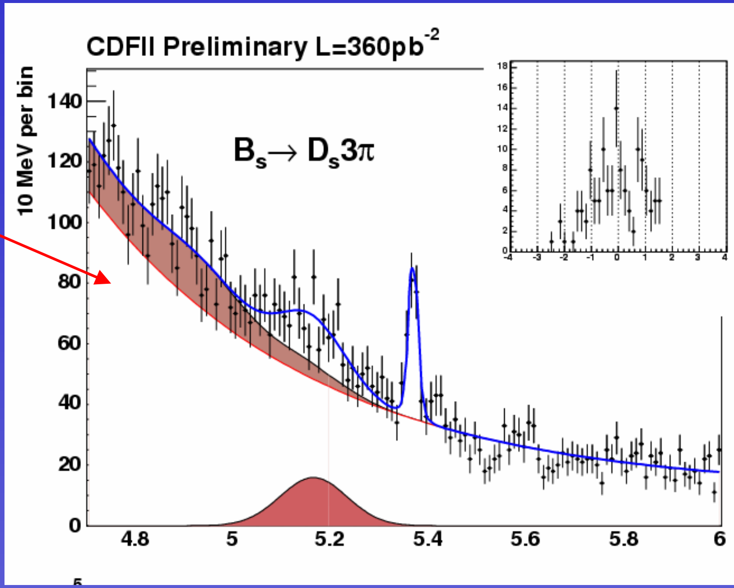




Future perspectives

Future perspectives

- Add more channels
  - $B_s \rightarrow D_s 3\pi$ (130 events +20%)
  - $B_s \rightarrow D_s^* \pi$
- Add semileptonic B_s decays from the hadronic trigger (S. De Cecco talk) X2 semileptonic statistic

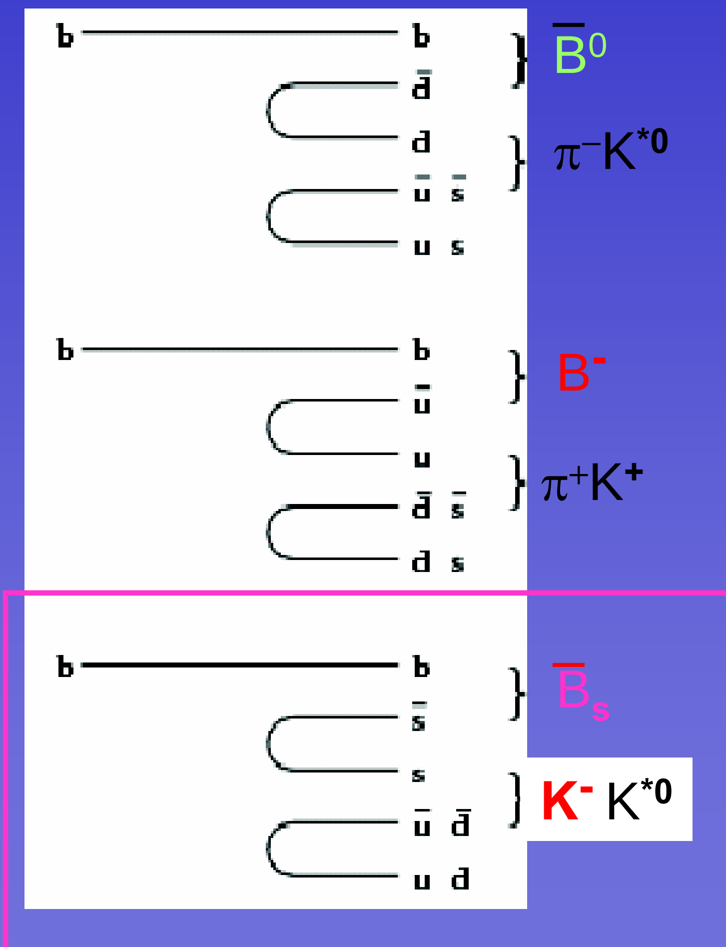


- Improve decay time resolution with PV event by event (detail)
- Incremental changes in existing algorithm (new Jet Charge +20% εD^2)
- Add new tagging algorithm Same Side Kaon Tag

- New data rolling in, but increasingly peak luminosity:
  - Keep alive as much as possible present triggers → SVT upgrade
  - Use new trigger strategies
    - 2 SVT Tracks + opposite side muon (pt>1.5 GeV) at trigger level (already in place since summer 2004 can survive at higher luminosity)

Same side Kaon tagging

Exploits the charge correlation between the b quark flavour and the leading product of b hadronization.



Already used in Δm_d measurement, gives an εD^2 = 1.1 ± 0.4 %

B^+ case is complicated by the contribution of excited B_d and B_s states

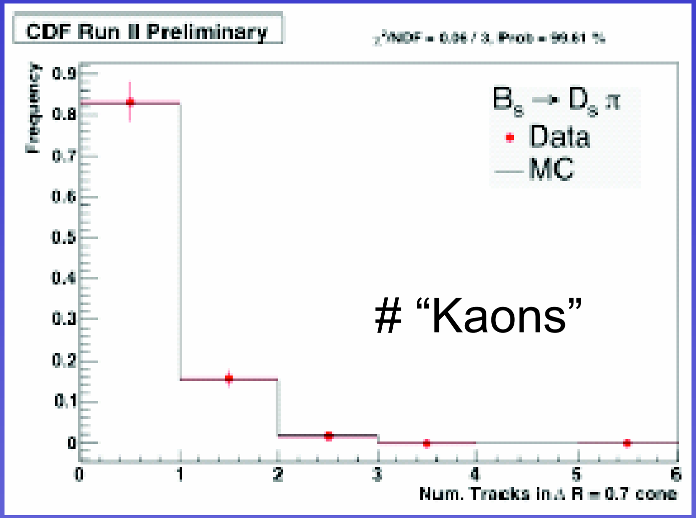
SS Kaon tag possible with PID

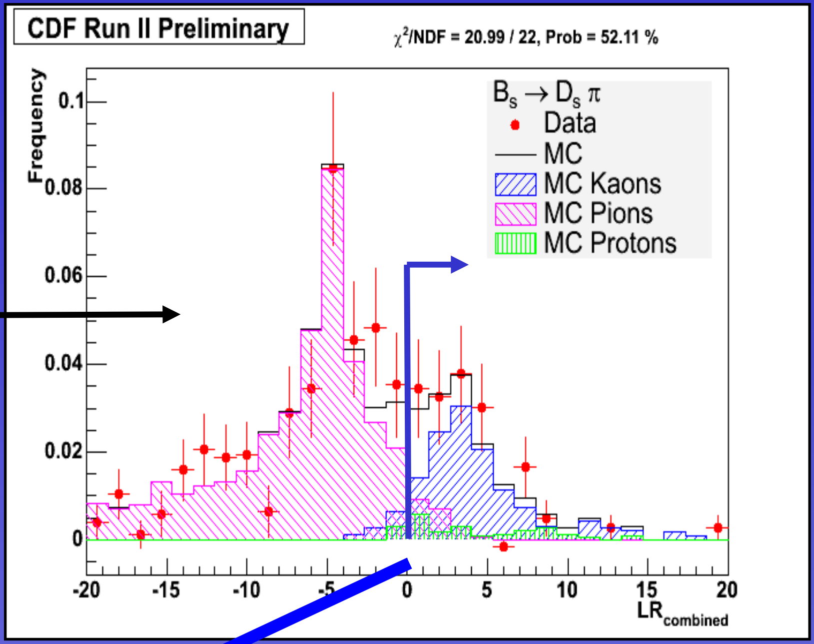
Issues:

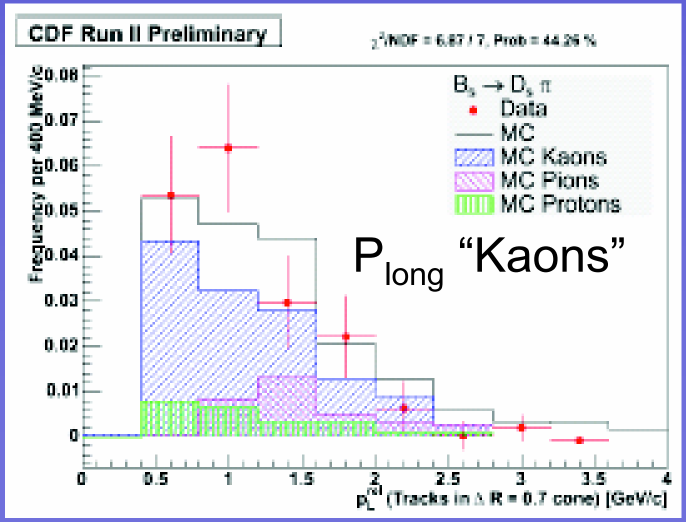
- Unlike opposite side tagger cannot calibrate using B^0 and B^+
- Need to know εD^2 from MC to set a limit on Δm_s
  - MC tuning crucial

MC-data comparison with PID

<u>Apply PID</u>, **T.O.F.** and **dE/dx** combined
In a Likelihood ratio **L(K)/L(π)**







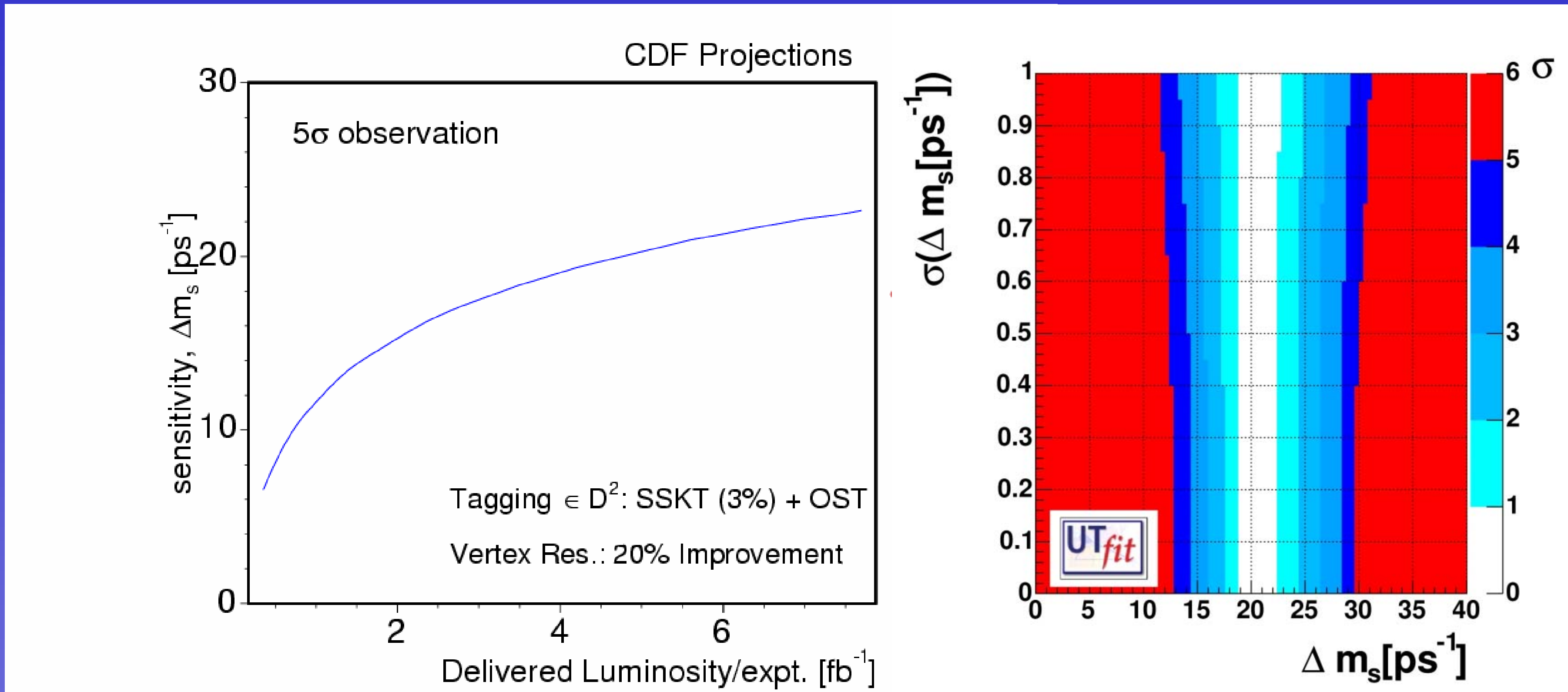
Encouraging agreement!

<u>Issues:</u>

- *Particle fractions in MC*
- *PID resolution tuning*
- *Backgrounds*

- *MC predict εD^2 can be 2-3%*

B_s mixing sensitivity projection



- Analytic extrapolation, reproduce present result with current inputs
- Prediction include a reduced (50%) effective luminosity usable for B-physics from 2007 onwards
- Sensitivity to the favorite CKM range
- In case of no signal 95% C.L. up to 30 ps^{-1} with 4 fb^{-1}
- CKM fit will imply New Physics if Δm_s>28 ps^{-1} by then…

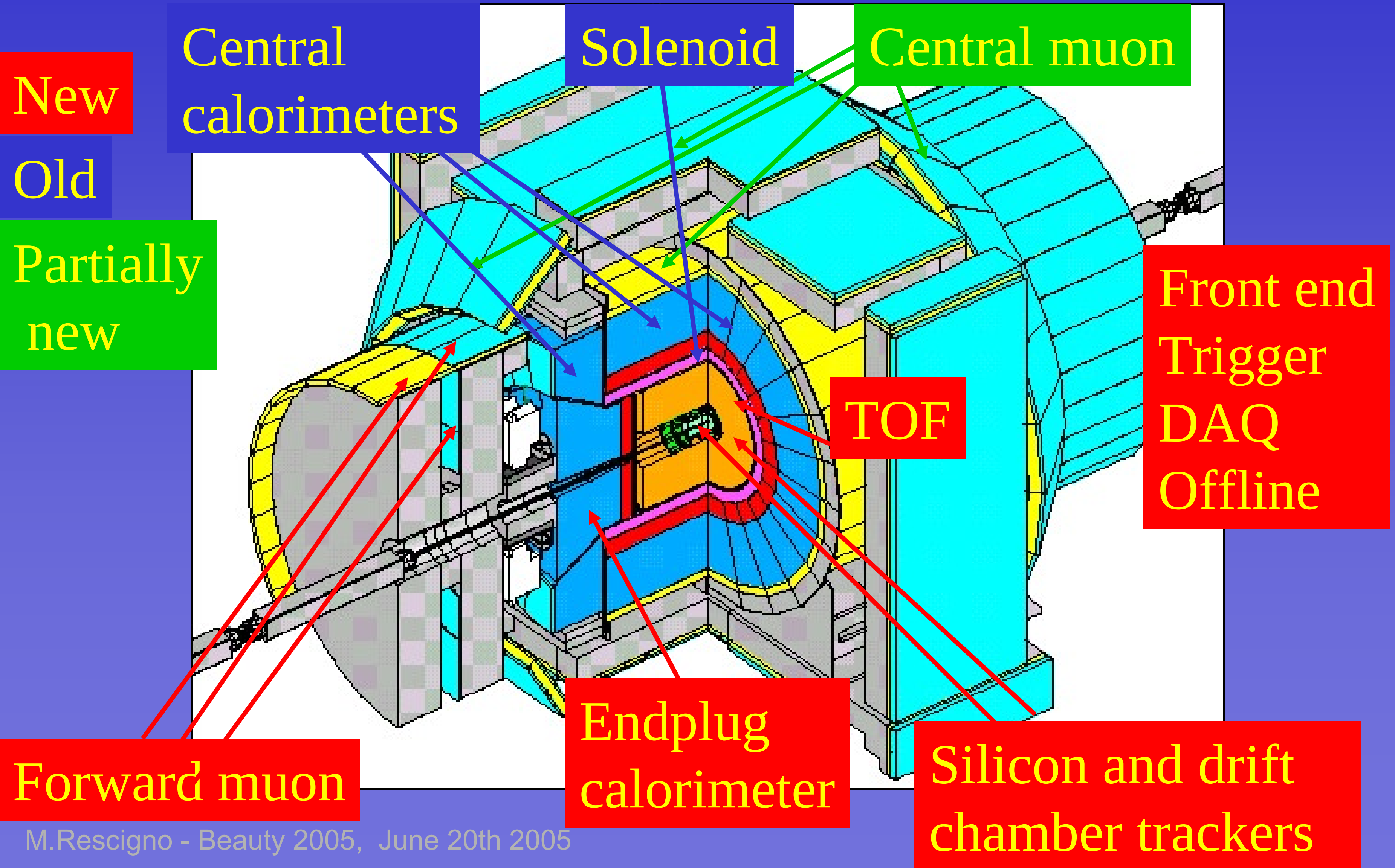
More projections

Summary

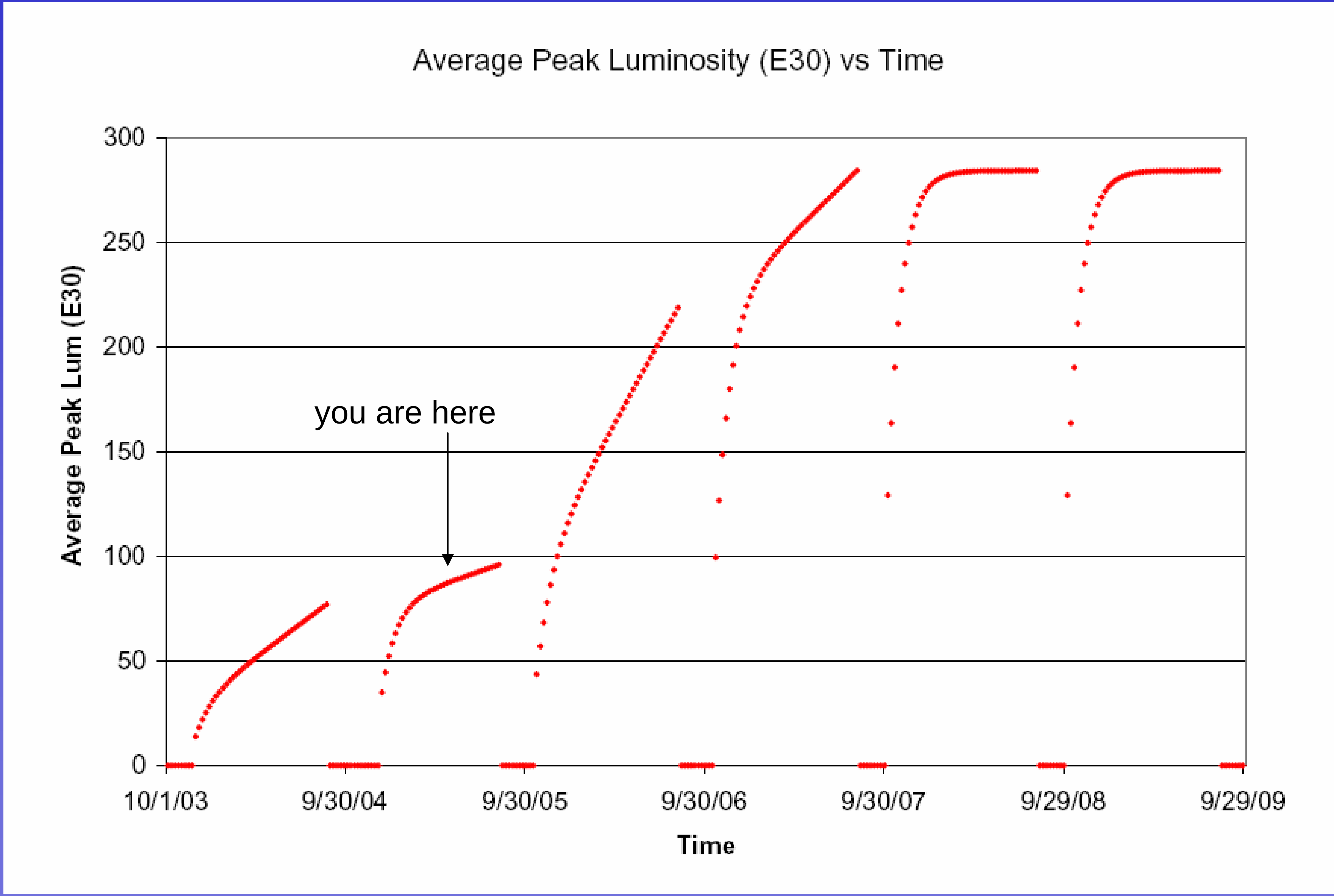
- First attempt at this (very) complex analysis!
- Expect close to 1fb^{-1} good data on tape by fall shutdown:
  - x3 statistics w.r.t to present result ?
  - Additional channels can be used both for fully reconstructed and semileptonic
  - Incremental improvements to existing opposite tagging algorithm expected
  - Building confidence on Same Side Kaon tagging
  - Better reconstruction of primary/secondary vertex improve proper time resolution
- Improved limit (15 ps^{-1} sensitivity?) expected by winter 06!
- Extensive upgrade to DAQ/trigger will keep B-triggers alive with increasing luminosity and allow the exploration of the SM favourite range for Δm_s by the end of RunII

Backup

The Upgraded CDF Detector

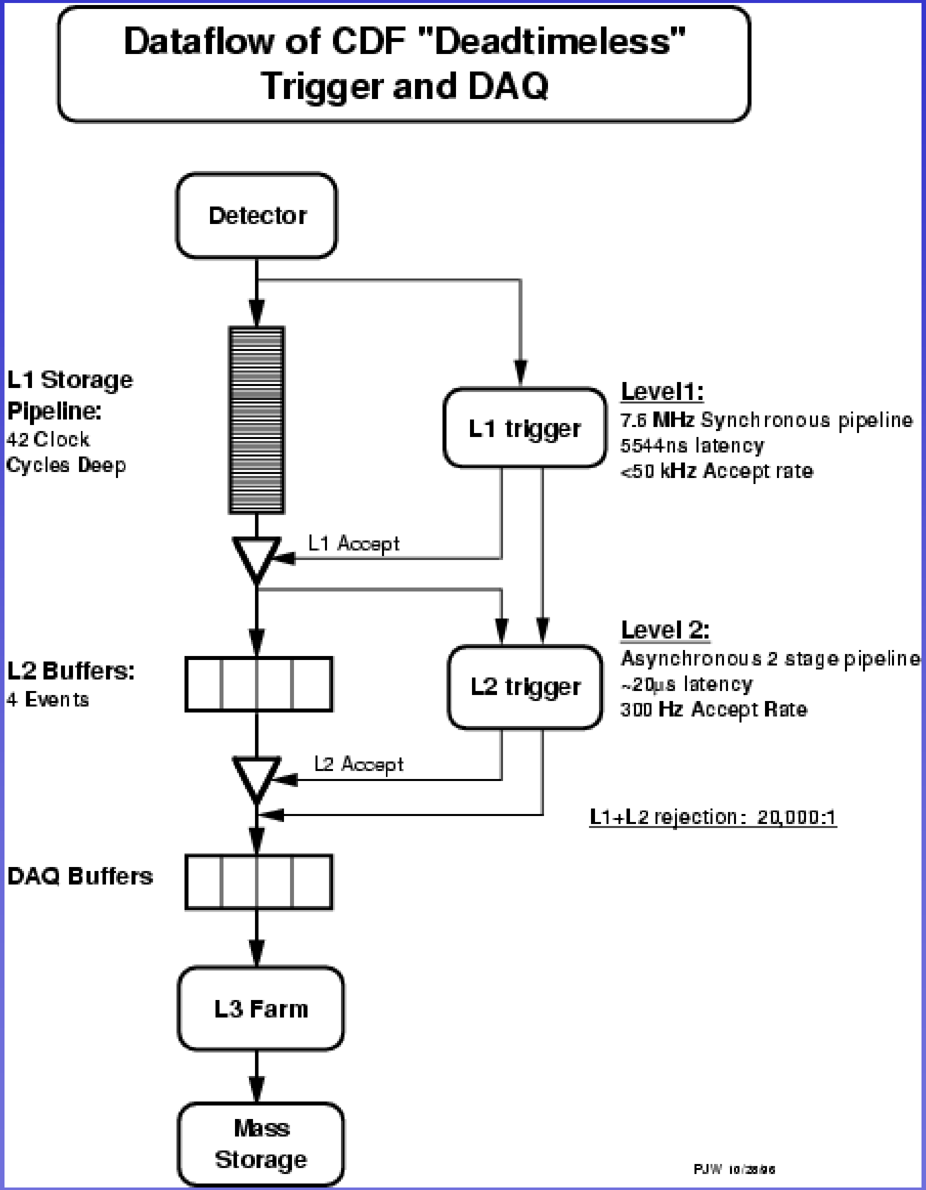


AD Projections (design plan)



CDF trigger architecture

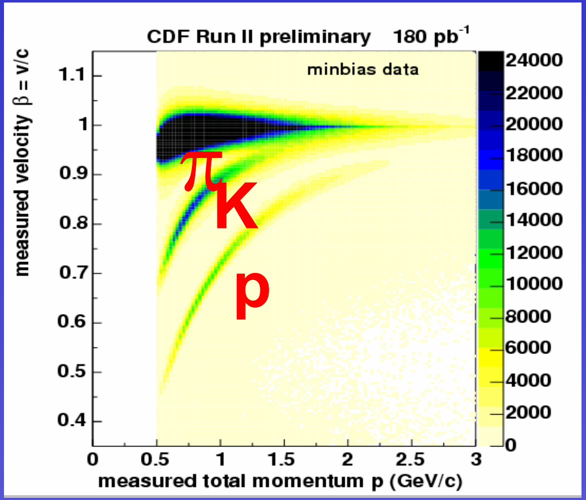
- Crossing: 396 ns: 2.5 MHz
- Level 1: hardware
  - Calorimeter, Muon, Track
  - 25kHz (reduction ~x100)
- Level 2: hardware + CPU
  - Cal cluster, Silicon track
  - 400 Hz (reduction ~x60)
- Level 3: Linux PC farm
  - ~ Offline quantities
  - 90 Hz (reduction ~ x5)



Basic tools: PID

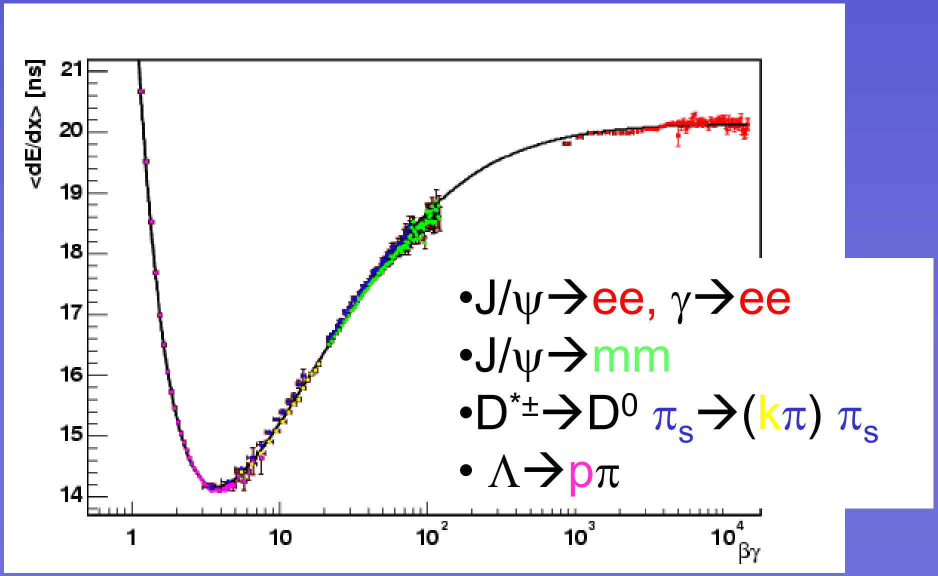
- Improved TOF calibration (better resolution) + t0 (reduced tails)

TOF: >1σ K/π separation up to p=2 GeV

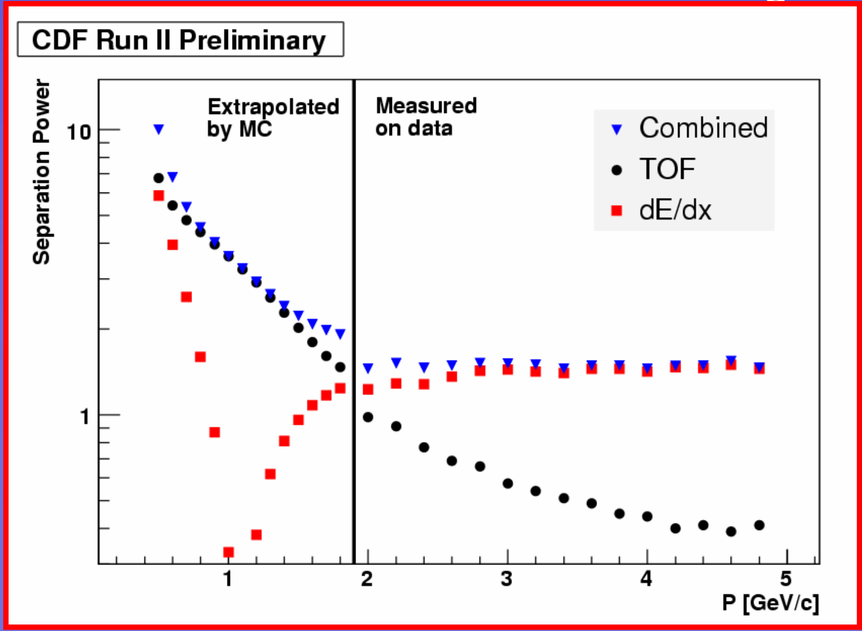


- Improved COT dE/dx calibration over wider βγ range

dE/dx in COT
K/π sep. >1.4σ@Pt>2GeV

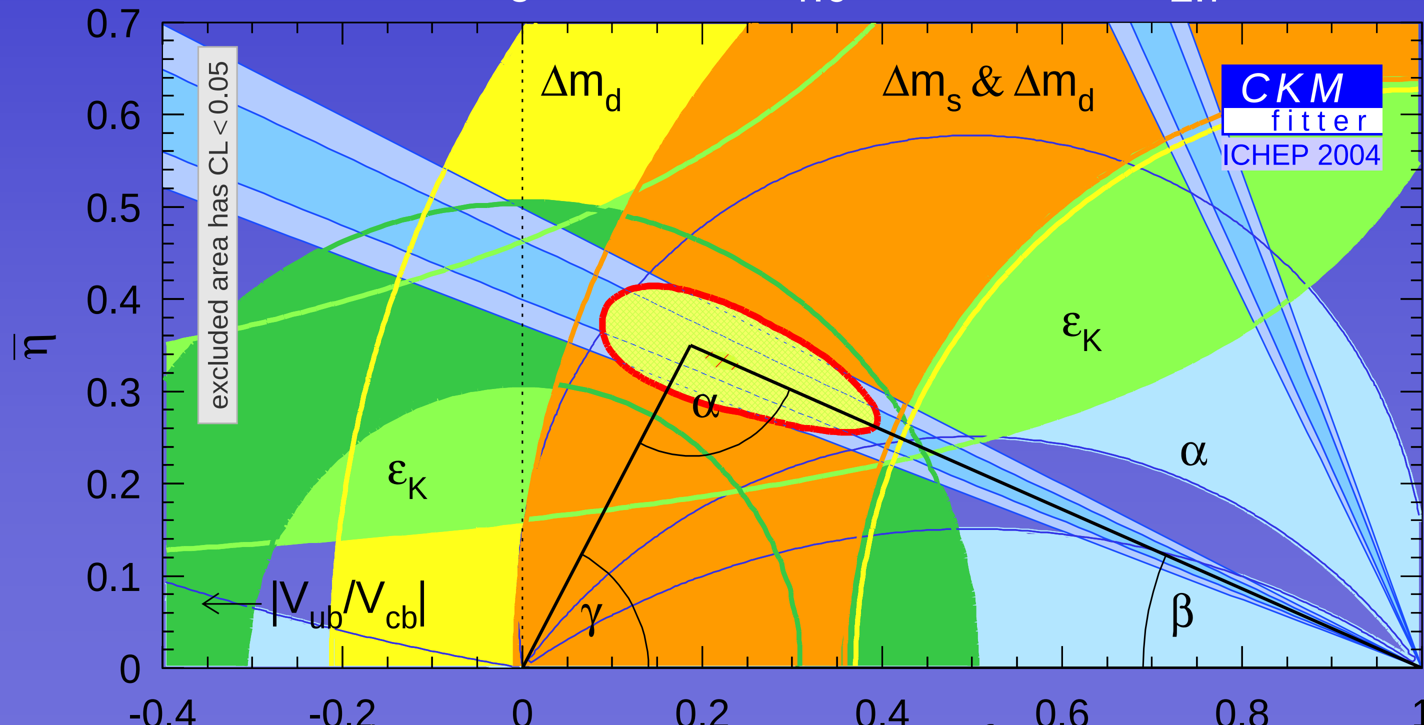


Combine TOF+COT in a likelihood ratio usable for all momentum range!



UT fit and Δm_s (CKMfitter)

- Yellow Band: Δm_d measurement: ~15% uncertainty
- Orange Band: Lower limit on Δm_s = Upper Limit on $|V_{td}|$
  – The lower limit on Δm_s already gives a constraint to the Triangle
- CKM Fit result: Δm_s: $17.8^{+6.7}_{-1.6}$ (1σ) : $^{+15.2}_{-2.7}$ (95%CL)



from Δm_d

Lower limit on Δm_s $\bar{\rho}$ from $\Delta m_d/\Delta m_s$

back

CDF "B_s Mixing Group"

- ~70 physicists (22 italians, 9 phd/post-doc) in CDF are actively involved in the B_s mixing project
  - – Improving the trigger strategy
  - – Understanding the detector
  - – B Lifetime Measurements
  - – Flavor Tagging
  - – B^0 Mixing
  - – B_s Mixing
- Big collaborative effort:
  - –Analyse 3 different datasets
  - –Reconstruct 0(20) different decay modes
  - –Perform 2 parallel analysis for both hadronic and semileptonic modes
  - –Study 4 different tagging algorithms
  - –TOF and dE/dx calibrations

CDF/ANAL/BOTTOM/CDFR/7531
Version 1.0
March 9, 2005

Result of Unblinded Δm_s Amplitude Scan Using Semileptonic $B_s^0 \to D_s^- \ell^+ \nu$ Decays

B_s^0 Mixing Group

Farrukh Azfar [19], Gary Barker [8], Gerry Bauer [13], Franco Bedeschi [11], Satyajit Behari [15], Stefano Belforte [12], Alberto Belloni [13], Eli Ben-Haim [7], Arkadiy Bolshov [13], Joe Boudreau [22], Massimo Casarsa [12], Pierluigi Catastini [11], Alessandro Cerri [5], Agnese Ciocci [11], David Clark [2], Saverio D'Auria [6], Saverio Da Ronco [20], Sandro De Cecco [10], Amanda Deisher [5], Francesco Delli Paoli [20], Simone Donati [11], Mauro Donega [16], Sinéad Farrington [18], Armando Fella [11], Ivan Furić [4], Stefano Giagu [10], Karen Gibson [3], Kim Giolo [14], Gavril Giurgiu [3], Guillelmo Gomez-Ceballos [9], Robert Harr [24], Matt Herndon [15], Todd Huffman [19], Boris Iyutin [13], Matthew Jones [14], Ilya Kravchenko [13], Joe Kroll [21], Tom LeCompte [1], Claudia Lecci [8], Nuno Leonardo [13], Donatella Lucchesi [20], Petar Maksimović [15], Stephanie Menzemer [13], Jeffrey Miles [13], Michael Morello [11], Reid Mumford [15], Steve Nahn [25], Rolf Oldeman [18], Manfred Paulini [3], Christoph Paus [13], Jónatan Piedra [9], Kevin Pitts [17], Giovanni Punzi [11], Jonas Rademacker [19], Azizur Rahaman [22], Marco Rescigno [10], Alberto Ruiz [9], Giuseppe Salamanna [10], Fabrizio Scuri [11], Marjorie Shapiro [5], Paola Squillacioti [11], Masa Tanaka [1], Vivek Tiwari [3], Fumi Ukegawa [23], Satoru Uozumi [23], Denys Usynin [21], Ivan Vila [9], Barry Wicklund [1], Chun Yan [25]

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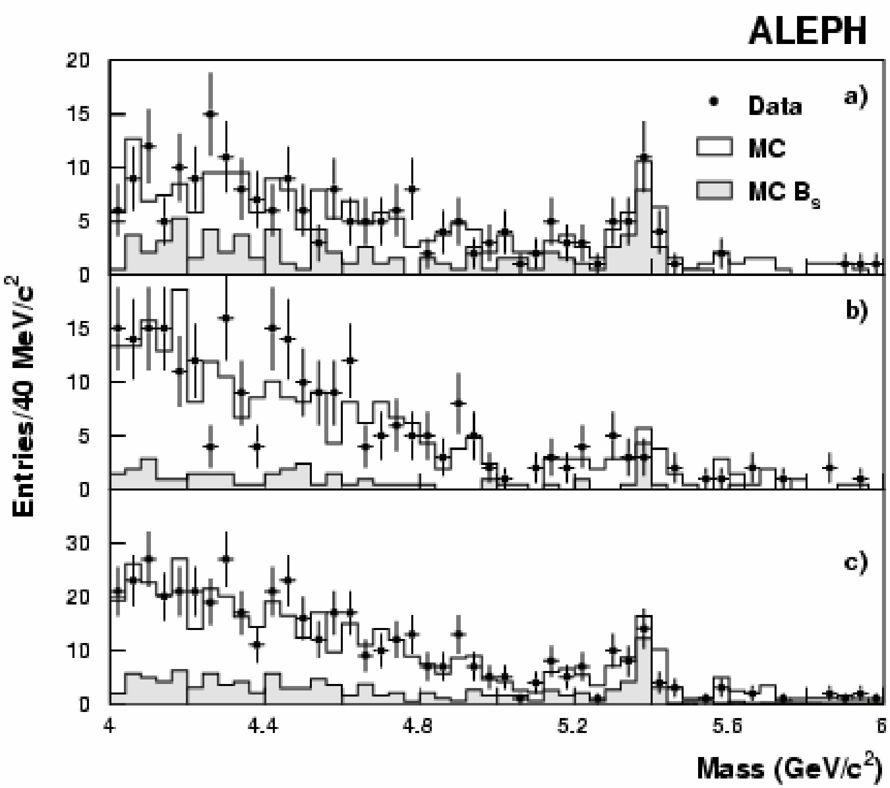
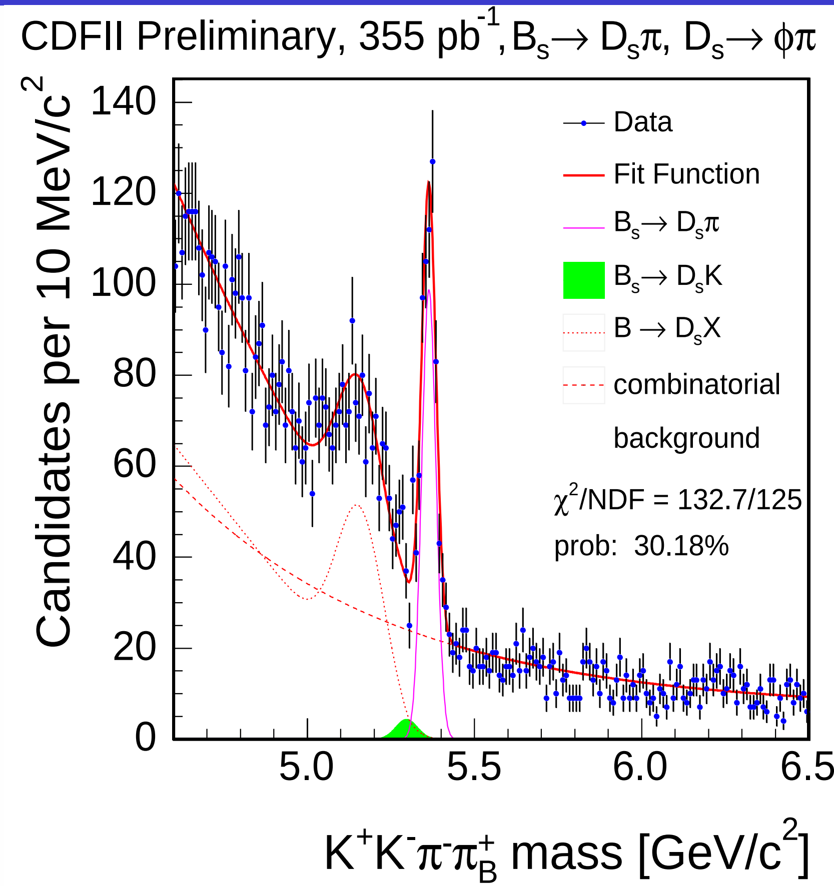
(11) Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, I-56100 Pisa, University of Siena, I-53100 Siena, Italy

Hadronic B_s CDF vs Aleph





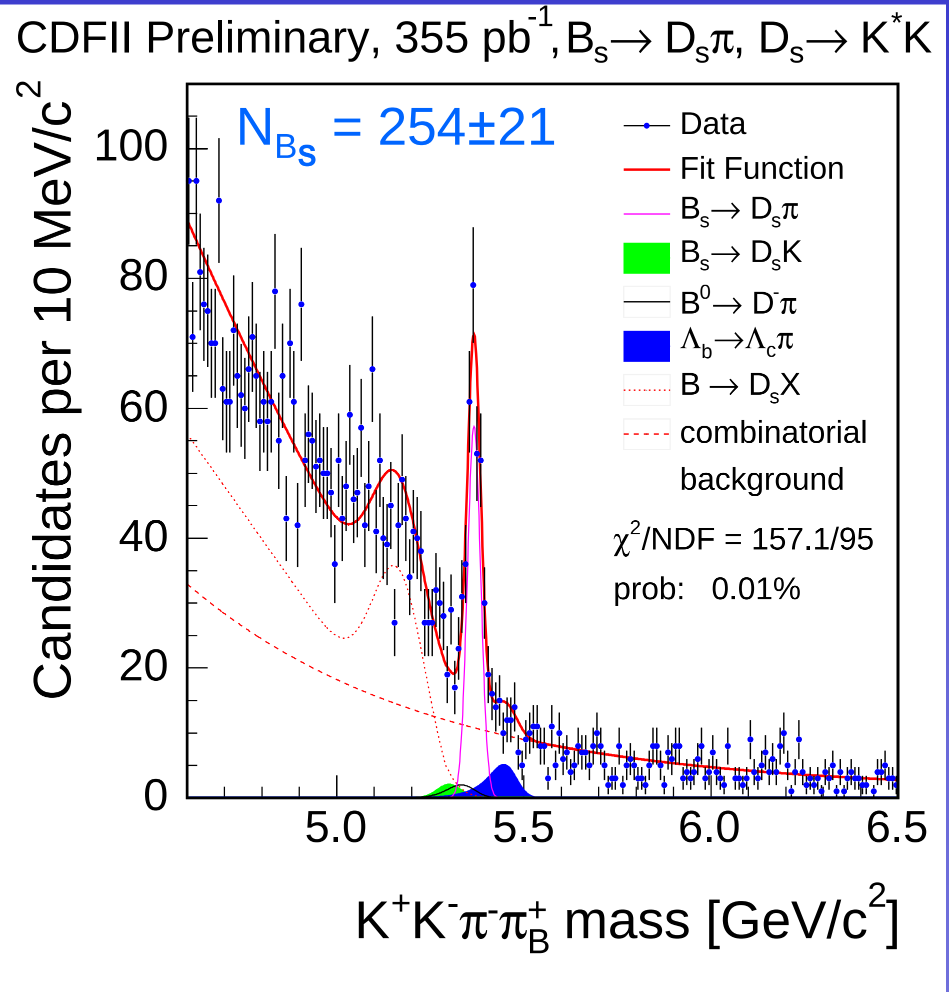
~30 events

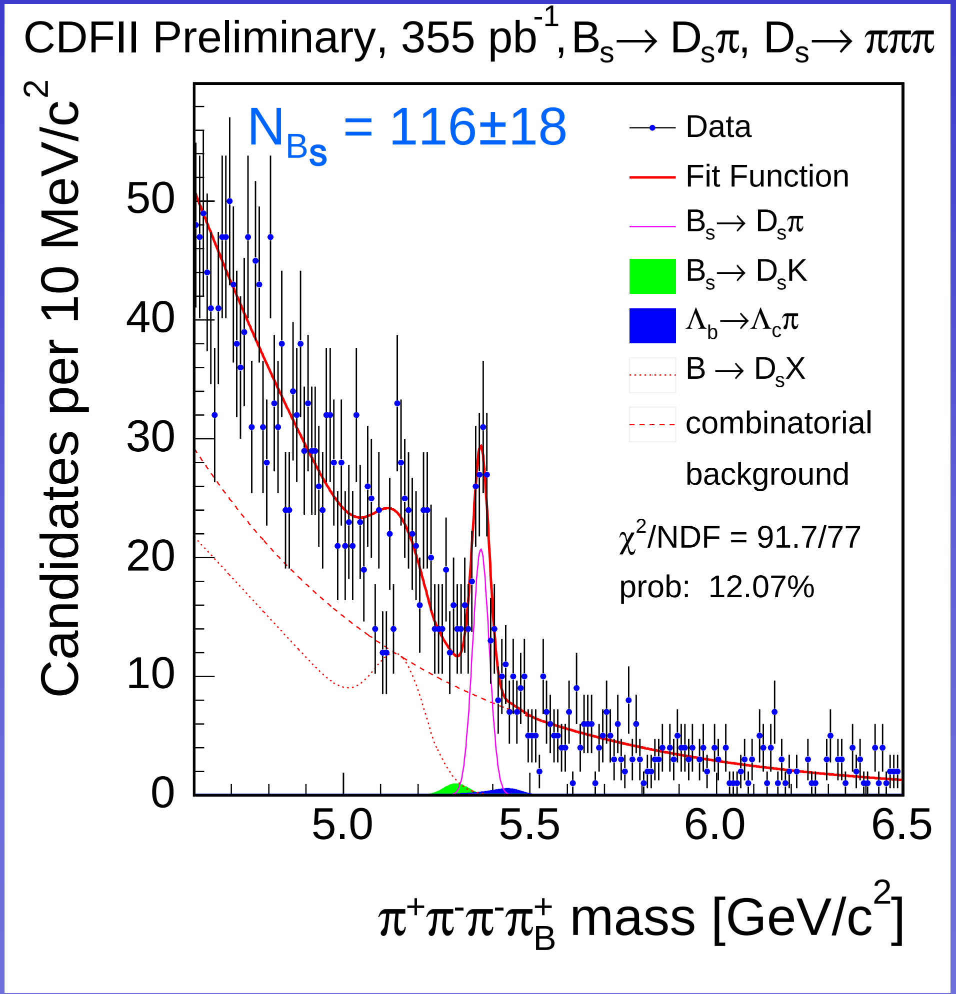
~500 events

Hadronic B_s signals (2)

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

$B_s^0 \to D_s^- \pi^+ (D_S^- \to \pi^+ \pi^- \pi^-)$



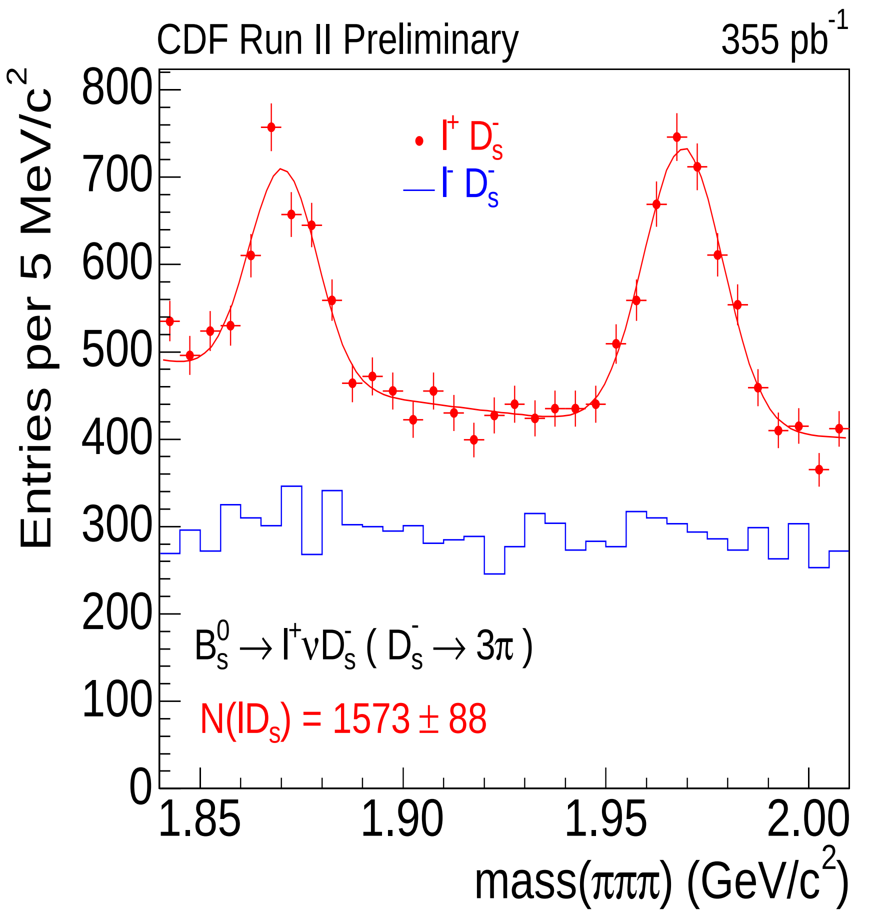


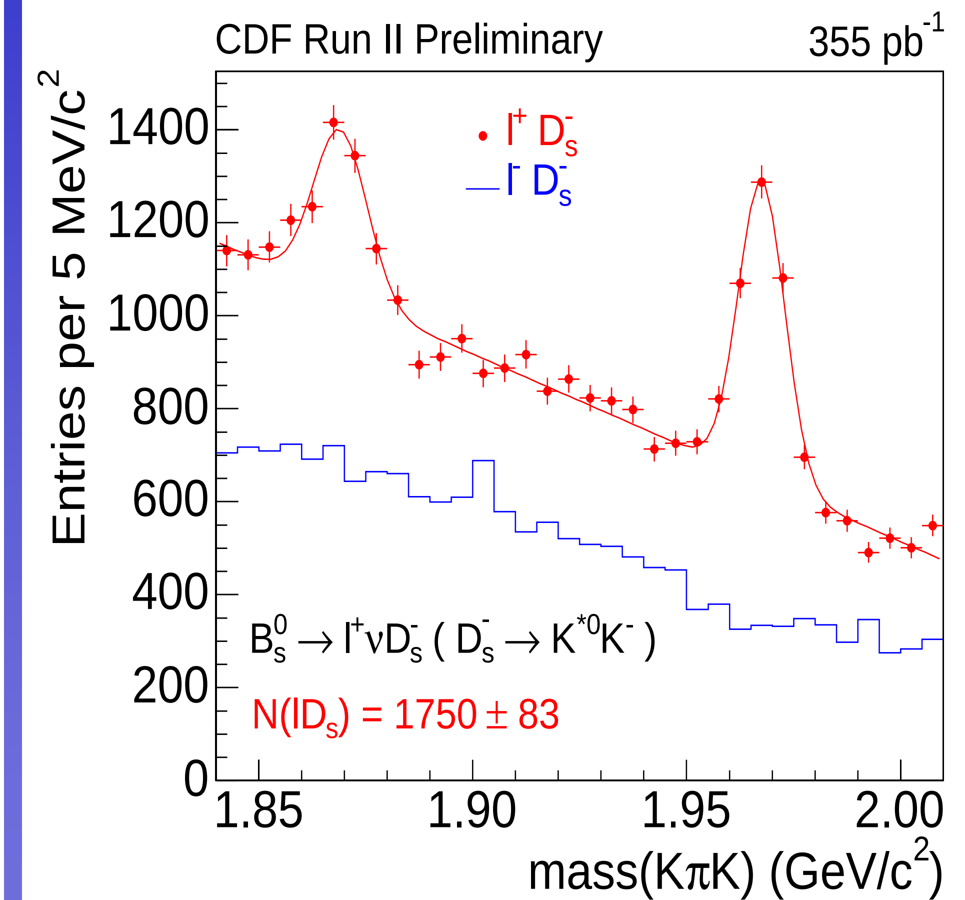
back

Semileptonic B_s Signals (2)

$$B_s^0 \to D_s^- l^+ \nu (D_S^- \to K^{*0} K^-)$$

$$B_s^0 \to D_s^- l^+ \nu (D_S^- \to \pi^- \pi^+ \pi^-)$$





1573±88 events

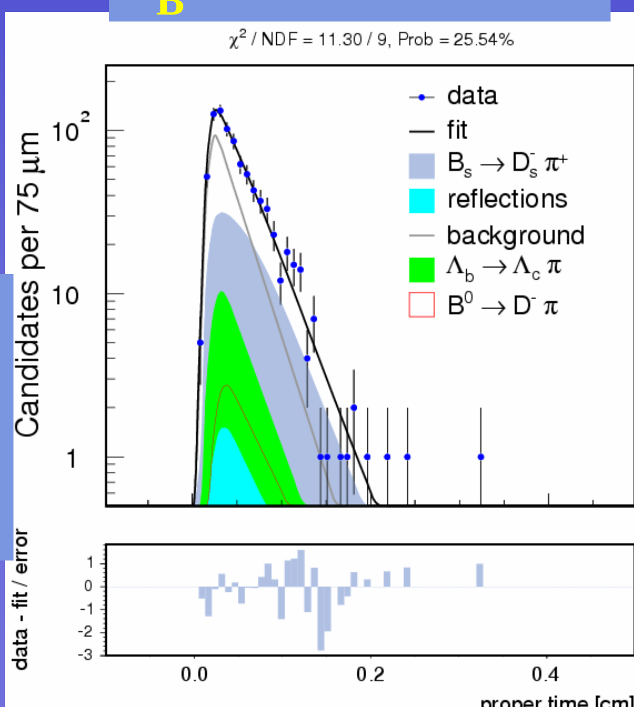
1750±83 events

B_s lifetime checks hadronic sample

- Raw lifetimes from mixing fit – not good for averaging
  - Average: τ_B = 1.515±0.070 ps no systematics evaluated
    - D0: τ(Bs) = 1.420±0.043±0.057 ps, WA: τ(Bs) = 1.469 ± 0.059 ps

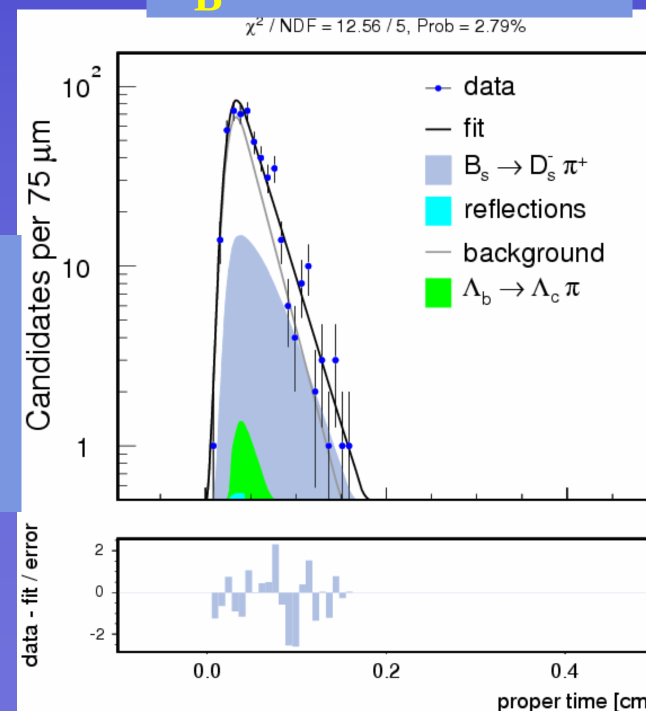
τ_B = 1.550±0.131

Ds→K*K

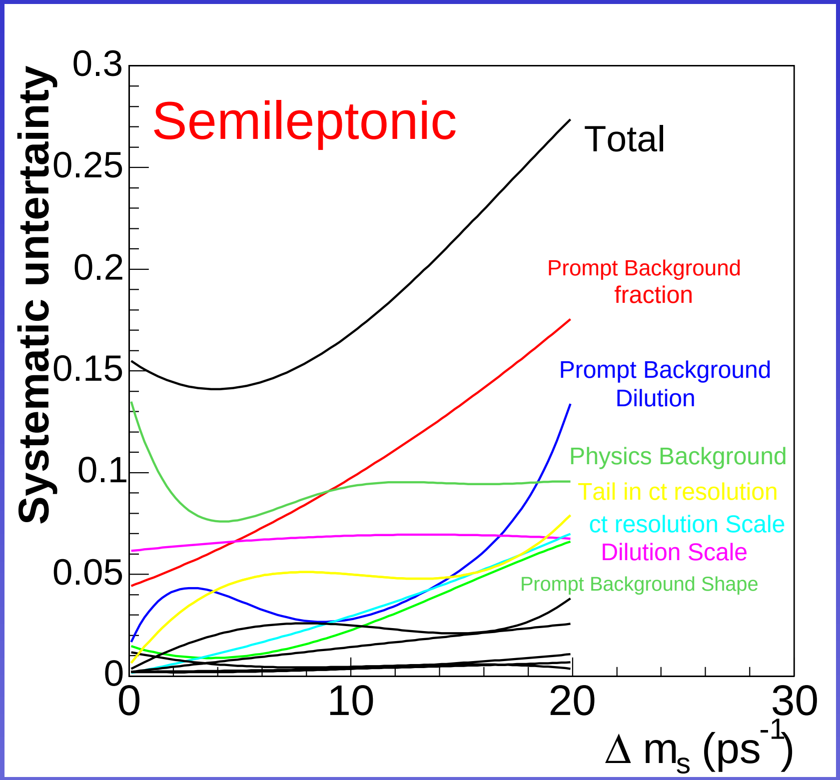


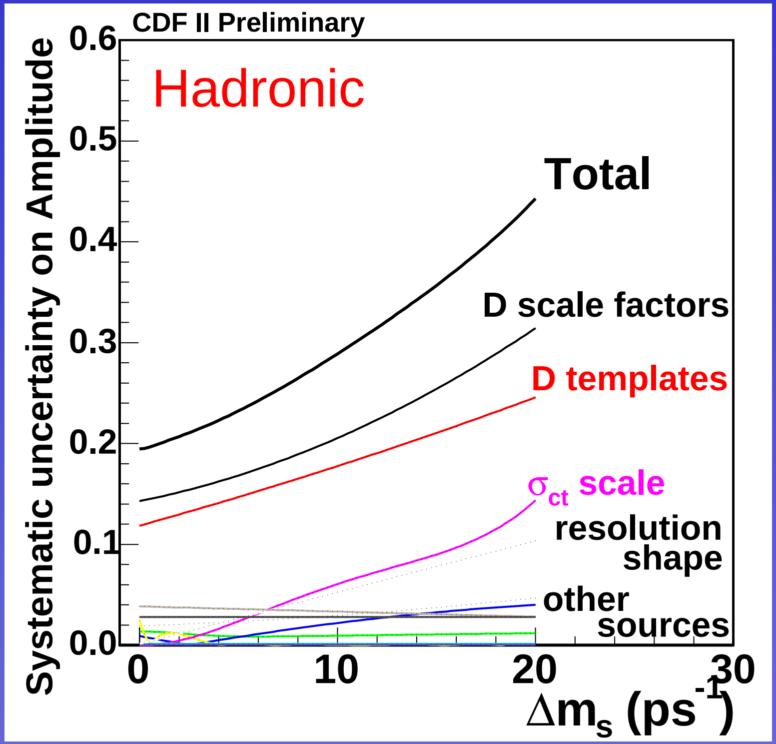
τ_B = 1.377±0.186

Ds→πππ



Systematic Uncertainties





- **Physics** background at low Δm_s
- **Prompt** background at high Δm_s

- **Dilution scale factors** and templates systematic limited from control sample statistics

Systematic errors **are negligible** with respect to statistical in both cases

back

Systematics Summary Table (Hadronic)

source	selected Δm_s scan points				
	0.0	5.0	10.0	15.0	20.0
$B_s \to D_s K$ level	0.019	0.024	0.030	0.037	0.047
dilution scale factors	0.143	0.168	0.205	0.254	0.314
dilution templates	0.119	0.147	0.178	0.211	0.246
fraction of Λ_b	0.014	0.009	0.009	0.011	0.012
Punzi term for σ_{ct}	0.009	0.008	0.022	0.033	0.030
dilution of $B \to DX$	0.025	0.001	0.000	0.000	0.001
σ_{ct} scale factor	0.000	0.024	0.061	0.090	0.144
usage of L00 in bias curve	0.001	0.001	0.001	0.001	0.001
Bs lifetime uncertainty	0.001	0.001	0.001	0.001	0.001
reweighted p_t spectrum	0.001	0.001	0.001	0.001	0.001
non-Gaussian tails in ct resol.	0.001	0.027	0.052	0.078	0.104
neglect B^0 in fit	0.039	0.036	0.033	0.031	0.028
effect of $\Delta\Gamma/\Gamma = 0.2$	0.028	0.028	0.028	0.028	0.028
Total systematic	0.195	0.232	0.289	0.357	0.443
Statistical	0.393	1.129	1.010	2.652	5.281

Systematics Summary Table (Semileptonic)

Source	selectex Δm_s scan points				
	0.0	5.0	10.0	5.0	20.0
Prompt background fraction	0.044	0.065	0.102	0.145	0.143
Prompt background dilution	0.014	0.040	0.027	0.062	0.157
Prompt background shape	0.015	0.010	0.019	0.054	0.057
Physics background fraction	0.134	0.078	0.093	0.096	0.103
Sample composition	0.002	0.015	0.022	0.021	0.039
Dilution scale factors	0.061	0.071	0.068	0.070	0.069
σ_{ct^*} scale factor	0.002	0.012	0.033	0.047	0.065
SVT bias curve	0.002	0.001	0.005	0.005	0.012
Primary vertex	0.007	0.003	0.003	0.005	0.007
B_s lifetime	0.001	0.011	0.014	0.020	0.026
non-Gaussian tails in ct resol.	0.005	0.047	0.049	0.052	0.078
effect of $\Delta\Gamma/\Gamma$=0.2	0.012	0.005	0.005	0.005	0.009
Total Systematics	0.156	0.142	0.167	0.220	0.273
Statistical	0.159	0.406	0.856	1.654	3.364

Dilution scale factor error

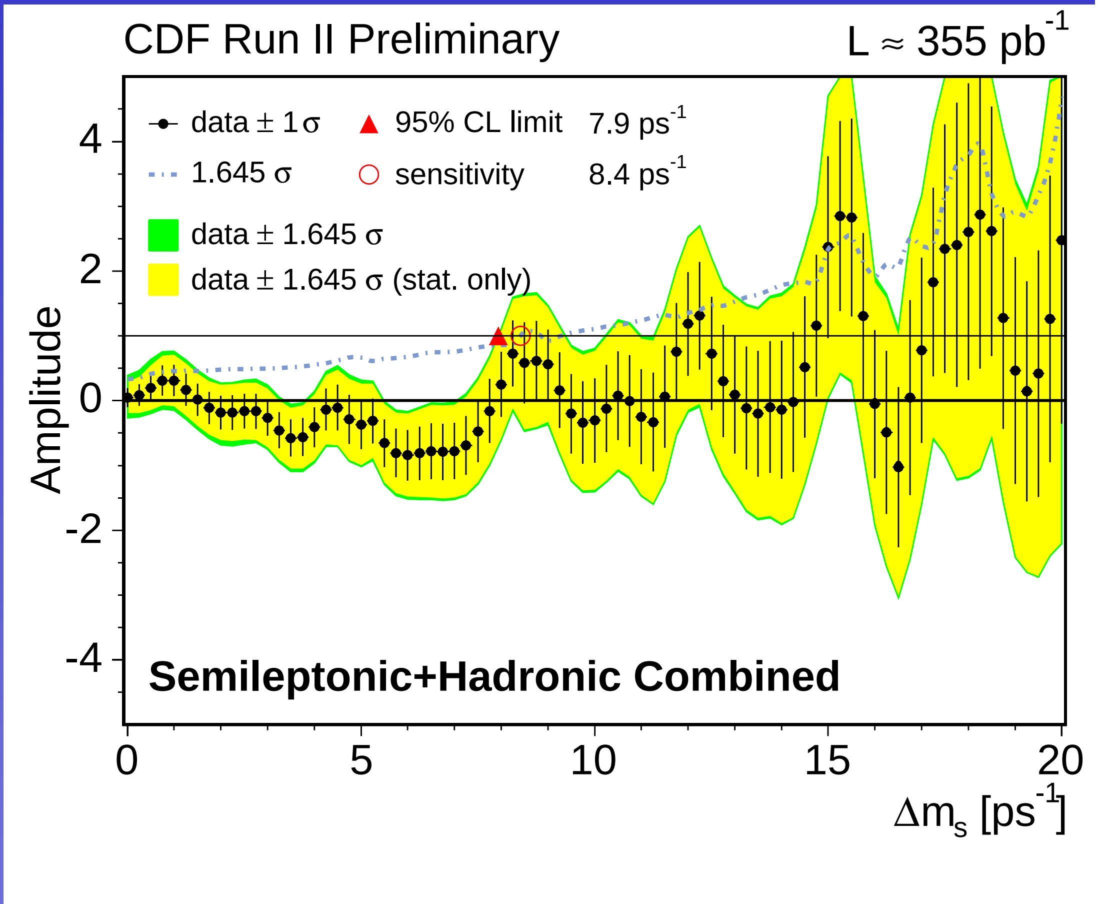
Error Source	S_D^{SMT} (%)	S_D^{SET} (%)	S_D^{JVX} (%)	S_D^{JJP} (%)	S_D^{JPT} (%)	Δm_d (ps^{-1})
σ_{ct}	0.01	0.02	0.01	0.06	0.04	0.0014
SVT efficiency	0.05	0.03	0.09	0.02	0.02	0.0008
SVT $d0$ resolution	0.26	0.20	0.49	0.22	0.19	0.0011
Combinatorial background	0.12	0.02	0.13	0.17	0.21	0.0019
Fraction of prompt bckg.	1.86	2.00	2.20	1.67	2.65	0.0041
Dilution of prompt bckg	1.30	1.40	2.40	4.00	8.00	0.0090
$c\tau_{B^{0,+}}$ fixed	0.22	0.15	0.19	0.13	0.29	0.0003
Sample composition	1.38	0.96	1.74	1.44	0.97	0.0089
Physics background	0.63	0.63	0.45	0.45	2.06	0.0027
Dilution templates	0.40	0.90	0.40	0.30	0.30	0.0060

TABLE III: Table of systematic uncertainties for the dilution scale factors and Δm_d.

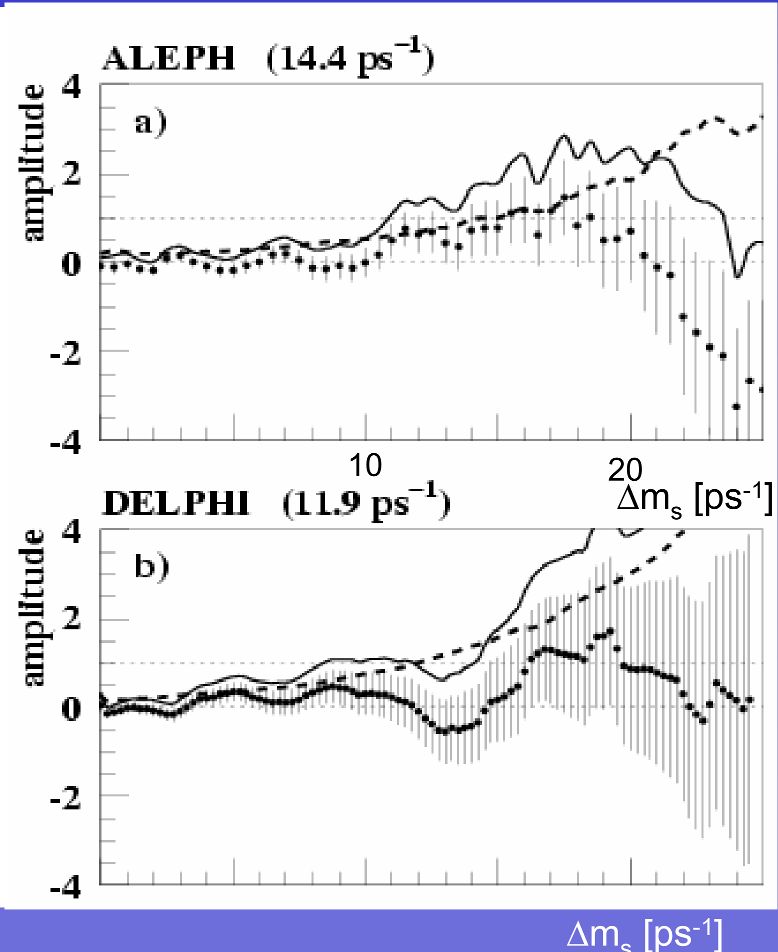
Source	Relative error (%)					
	S_D^{SMT}	S_D^{SET}	S_D^{JVX}	S_D^{JJP}	S_D^{JPT}	Δm_d
Mass Parameterization						
Signal shape for $B^0 \to D^-\pi^+$						
ratio of widths	–	–	0.1	0.5	–	0.3
fraction of wide Gaussian	–	–	0.3	0.4	–	0.1
Comb. backgr. for $D\pi$ modes	–	–	–	–	–	–
ct Parameterization						
MC lifetime in SVT bias	–	–	–	–	–	–
L00 in SVT bias	0.1	0.4	–	0.7	0.9	–
Impact parameter in SVT bias	0.2	0.2	0.2	0.4	0.5	–
Scale factor on σ_{ct}	–	–	–	–	–	–
Scale factor σ_{ct} for backgr.	–	0.2	0.4	–	0.1	–
Backgrounds						
K^{*0} swap in $B^0 \to J/\psi K^{*0}$	0.4	–	0.2	–	0.2	0.1
Λ_b in $B^0 \to D^-\pi^+$	–	0.2	–	0.1	–	–
B_s in $B^0 \to D^-\pi^+$	–	–	–	–	–	–
Dilution systematics						
binning of templates	3.2	4.3	3.0	0.1	0.1	0.5
statistical smear of templates	2.6	2.9	5.5	3.3	0.7	2.8
backgr. tagging efficiencies	0.3	0.2	0.2	0.8	0.2	–
Λ_b dilution in $B^0 \to D^-\pi^+$	–	0.4	–	0.2	–	0.1
Total	4.2	5.2	6.3	3.6	1.3	2.9

TABLE III: Summary of all systematic errors.

CDF vs LEP



CDF Run II Preliminary
L ≈ 355 pb-1
data ± 1σ
95% CL limit 7.9 ps-1
1.645 σ
sensitivity 8.4 ps-1
data ± 1.645 σ
data ± 1.645 σ (stat. only)
Amplitude
Semileptonic+Hadronic Combined
Δms [ps-1]

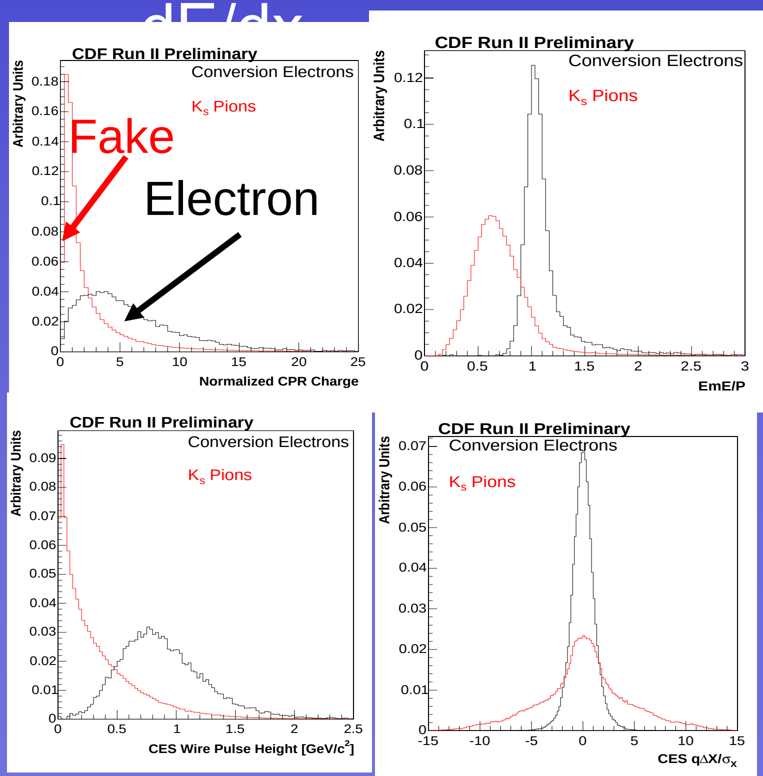


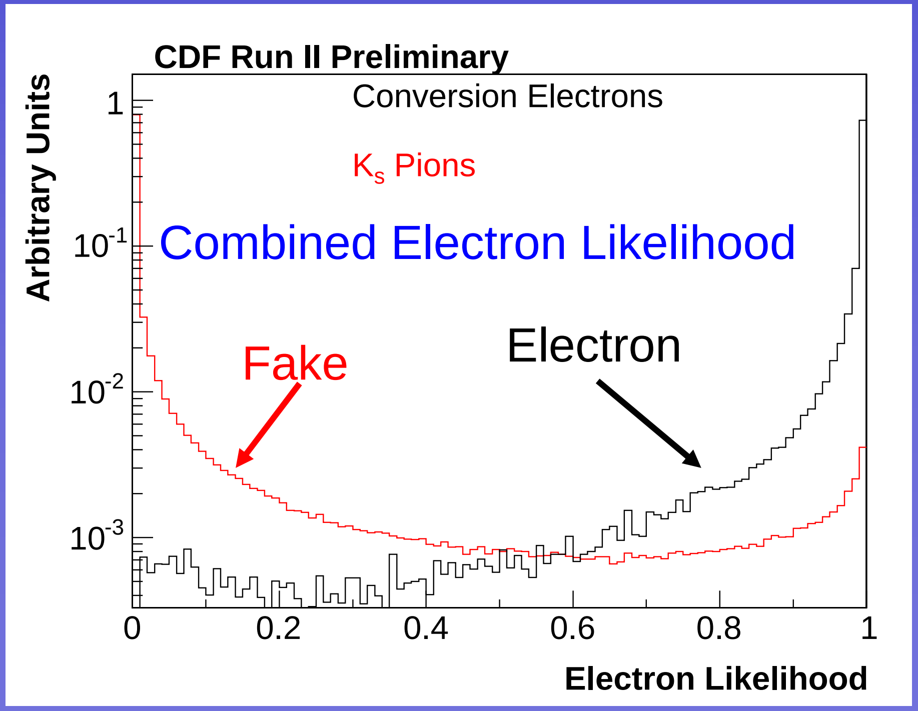
ALEPH (14.4 ps−1)
a)
amplitude
Δms [ps-1]
DELPHI (11.9 ps−1)
b)
amplitude
Δms [ps-1]

Likelihood Based Electron ID

- In CDF electron ID uses
  - ~10 parameters
  - Calorimeter, tracking, dE/dx
- Use likelihood to improve separation

$$S = \prod_i S_i \qquad B = \prod_i B_i \qquad L = \frac{S}{S+B}$$

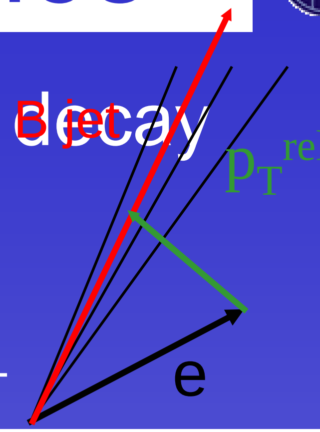


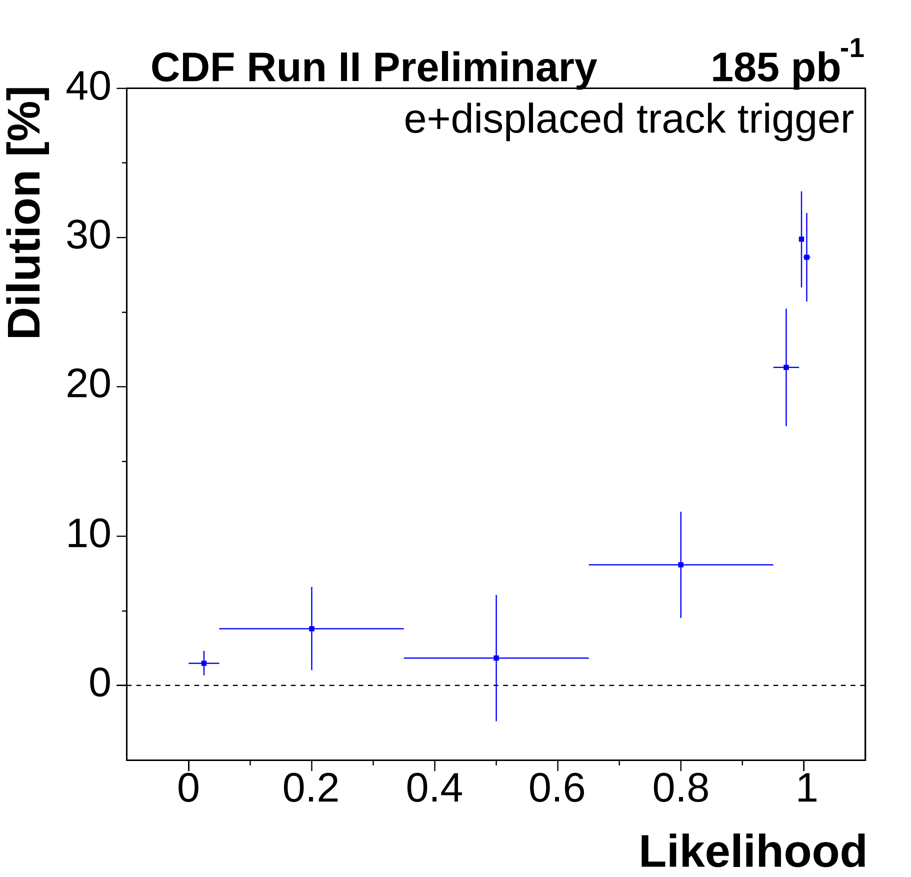


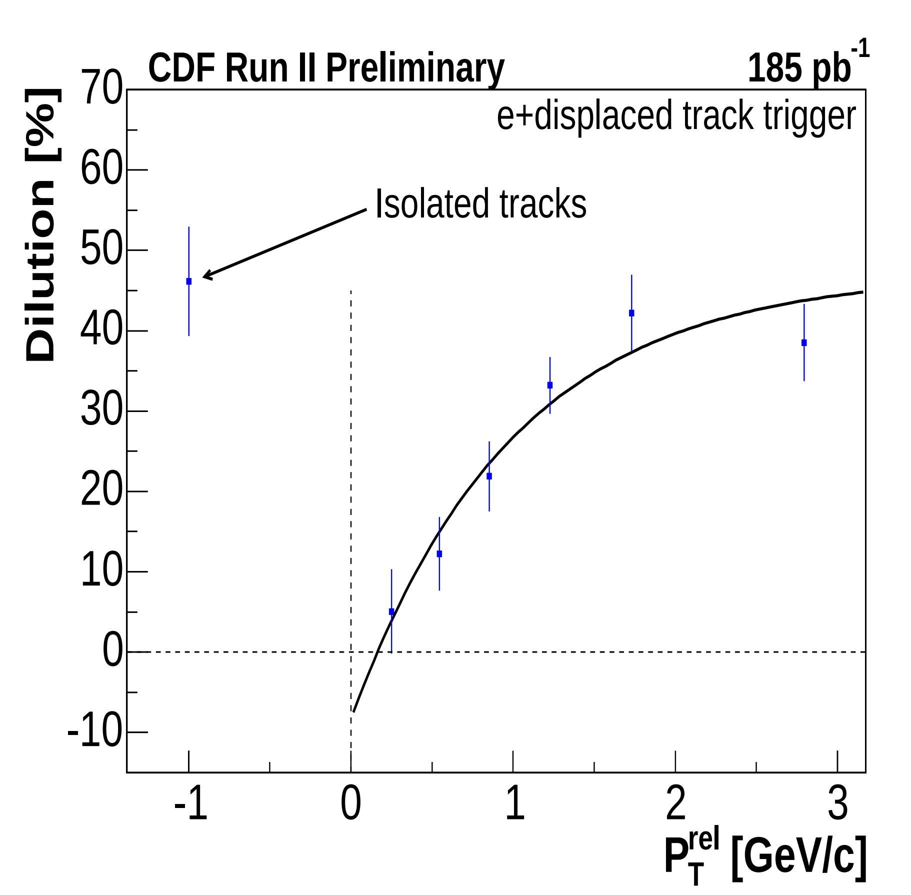
Electron Tag Performance

- For the Electron tagger, events are binnded in 2 parameters

- Sequential B decay
  - $b \rightarrow c + l^-$
    - Higer p_T^{rel}
  - $b \rightarrow c \rightarrow s + l^+$

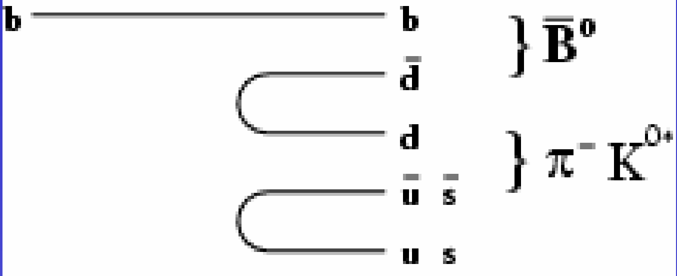




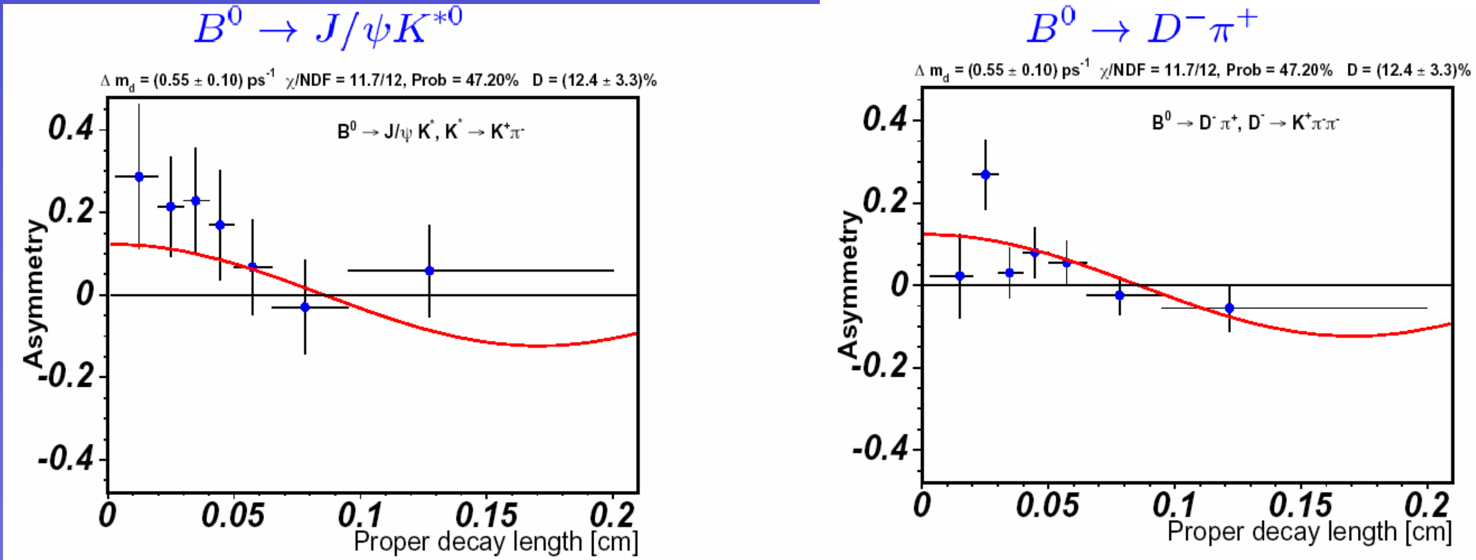


Same Side tagging B^0

Based on correlation between <u>charge</u> of <u>fragmentation π</u> and <u>flavor</u> of b in B meson

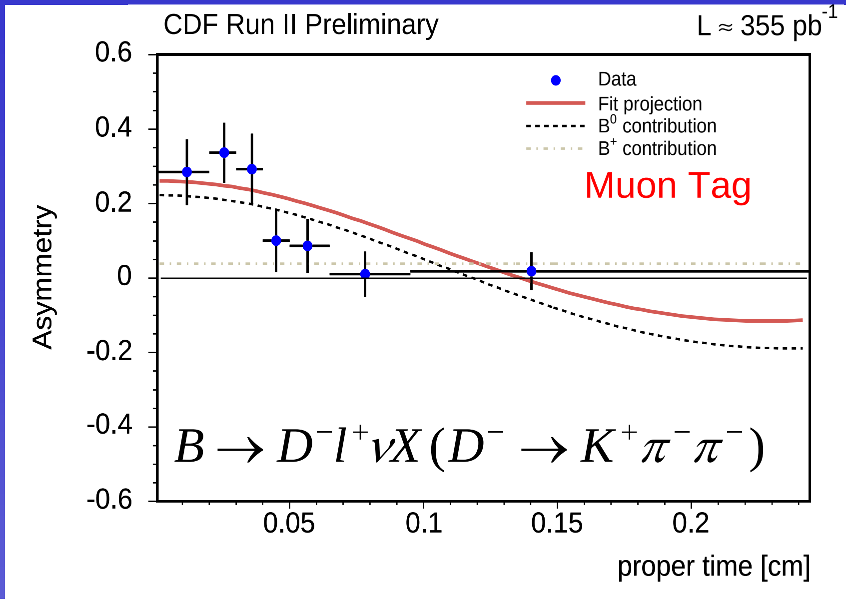


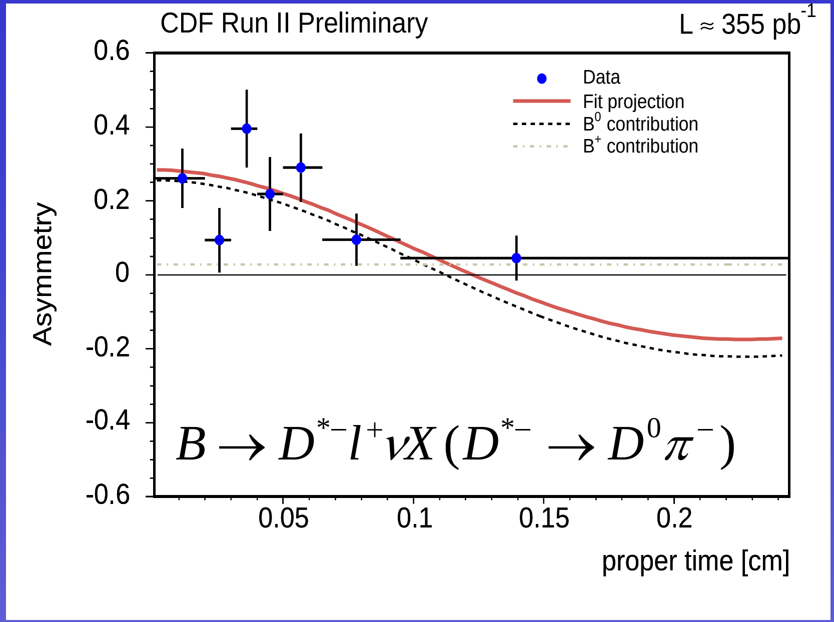
Run II PRELIMINARY 2004

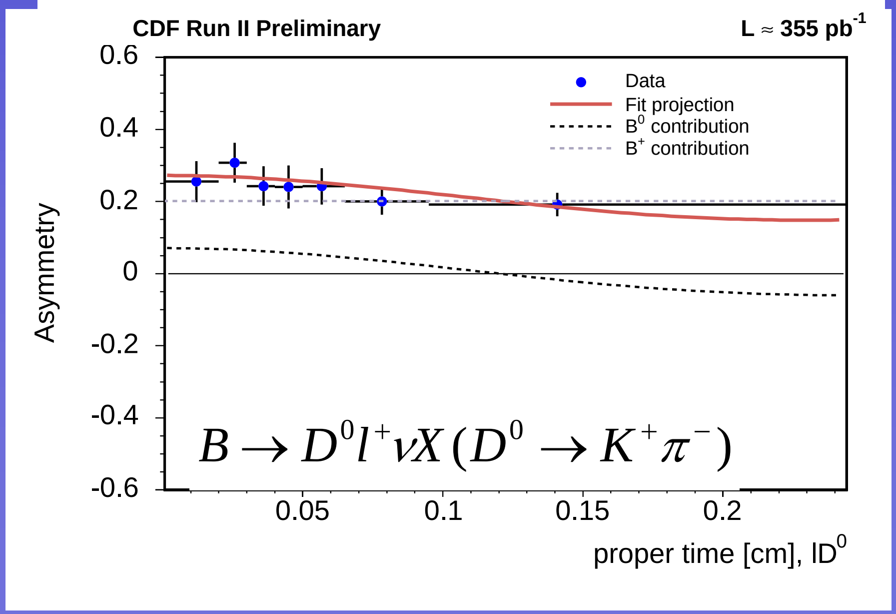


$\Delta m_d\ (ps^{-1})$	D_0 (%)	ϵD_0^2 (%)
0.55 ± 0.10	12.4 ± 3.3	1.0 ± 0.5

B^0 mixing in the semileptonic channels







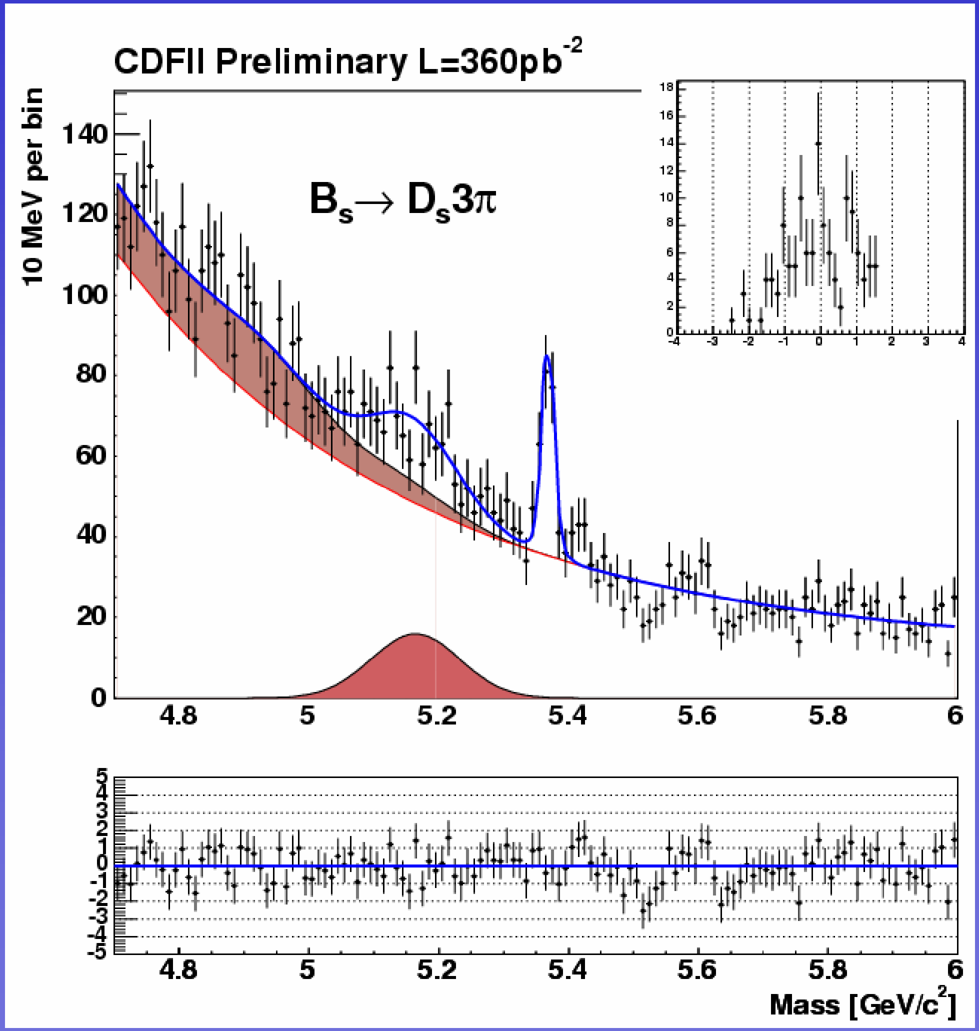
- Measure Δm_d
- Extract 5 dilution scale factors

→ The dilution scale factors are used for semileptonic B_s mixing analysis

Other channels, example

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

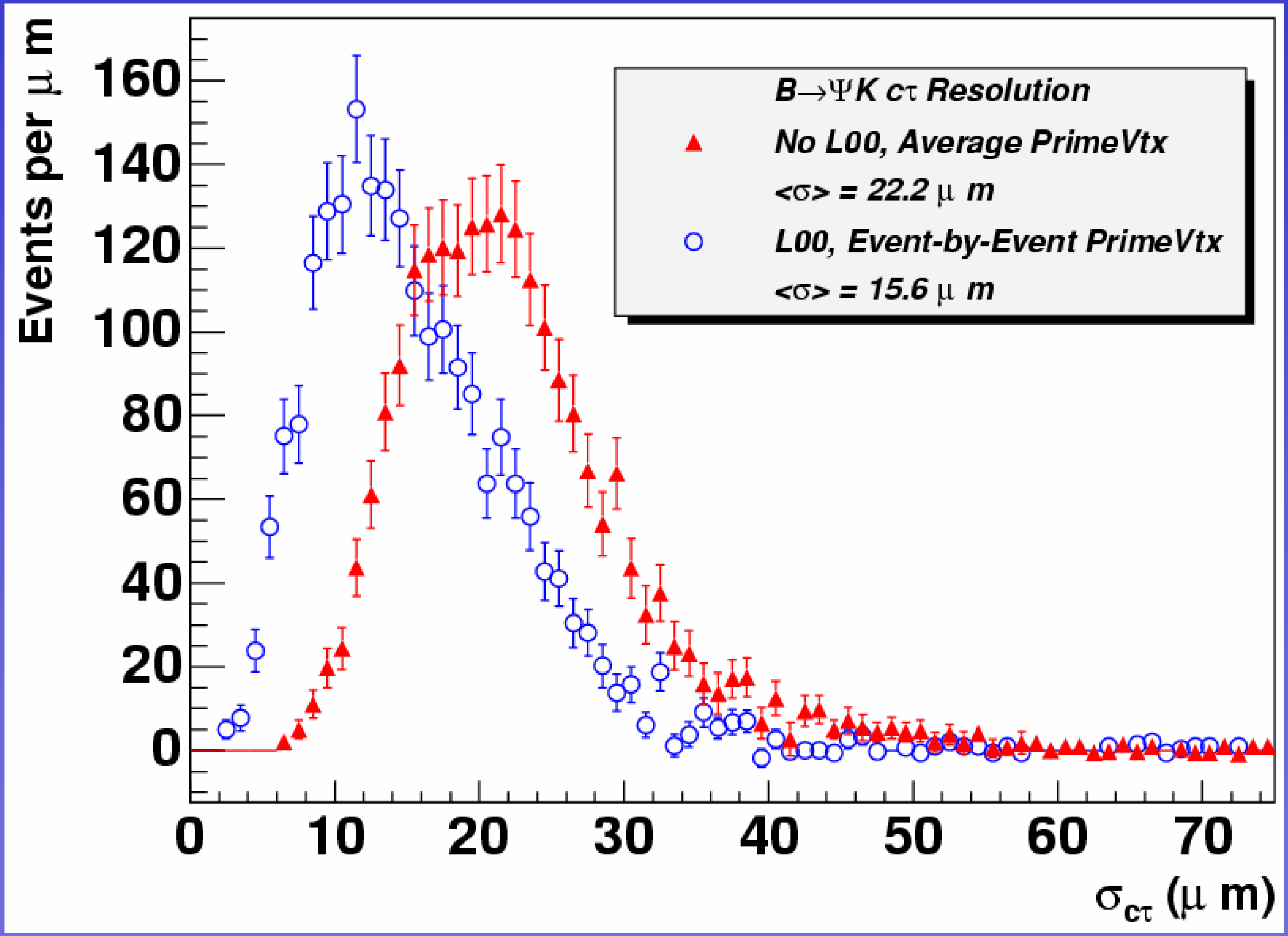
- 133±23 Bs candidates
- Already used for lifetime
- But not for mixing
- 20% statistics



example

cτ resolution improvements

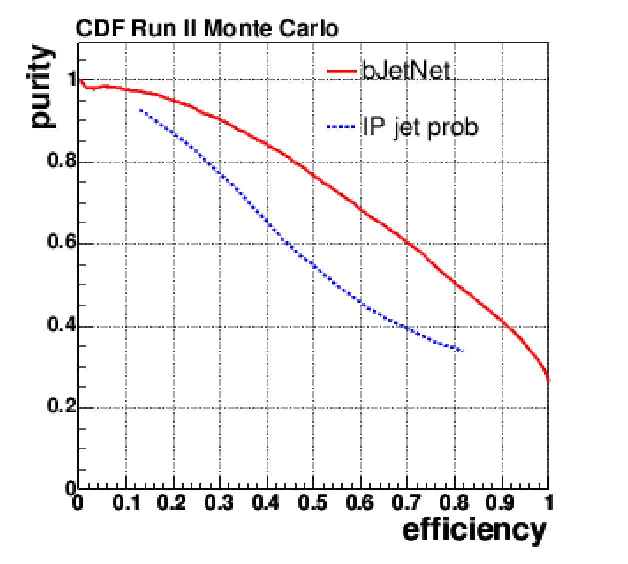
- No EbE/L00:
  - $\sigma \sim 67$ fs
- With EbE/L00:
  - $\sigma \sim 47$ fs
  - 30% improvement
- Not fully exploited yet (only L00)

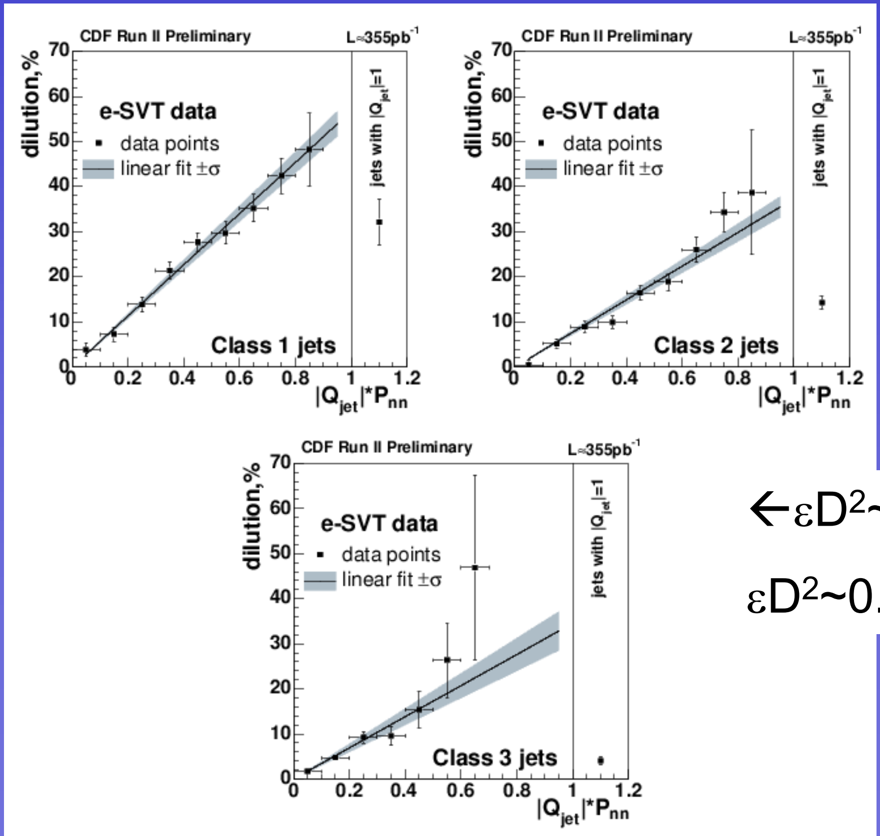


NNet Jet Charge

Nnet based

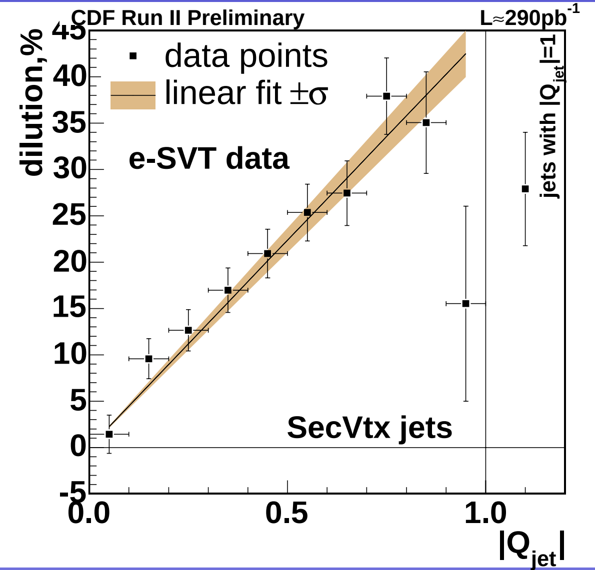
Wheight each track by its probability to originate from b





← $\varepsilon D^2 \sim 0.9$

$\varepsilon D^2 \sim 0.7$ →

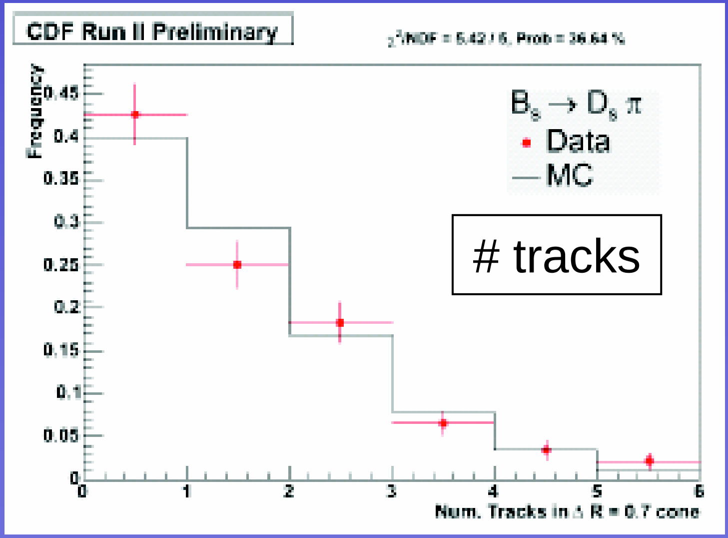


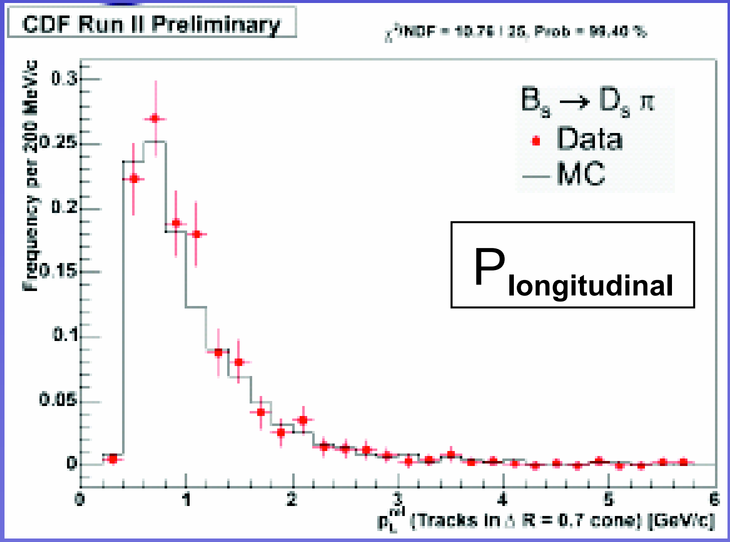
SSKT : MC tuning, no PID

One possible way to solve the issue of having a prediction for the SSKT dilution is to extract it from MC.

→Compare DATA with Pythia b-antib production and hadronization with all the processes on, underlying event "tune A" from HF x-sec. CDF data.

Look at the charged tracks in a cone of $\Delta R=0.7$ around the B_s (no PID)





good agreement !

B_s mixing sensitivity projection(II)

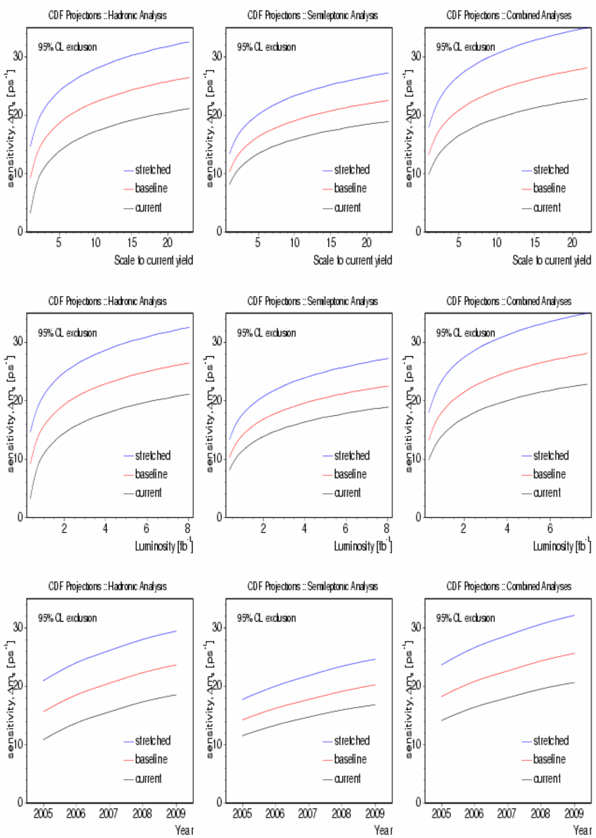


Figure 4: Sensitivity projections for 95% C.L. exclusion limit.

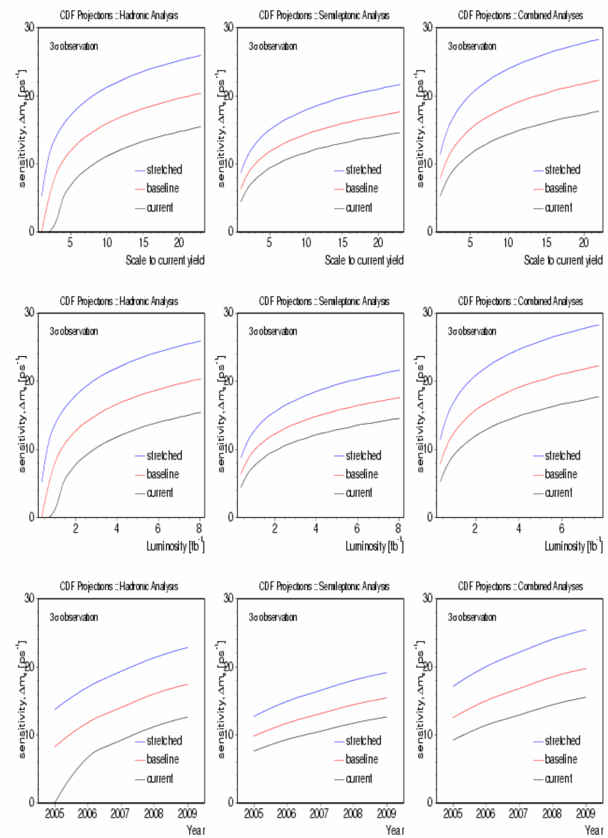
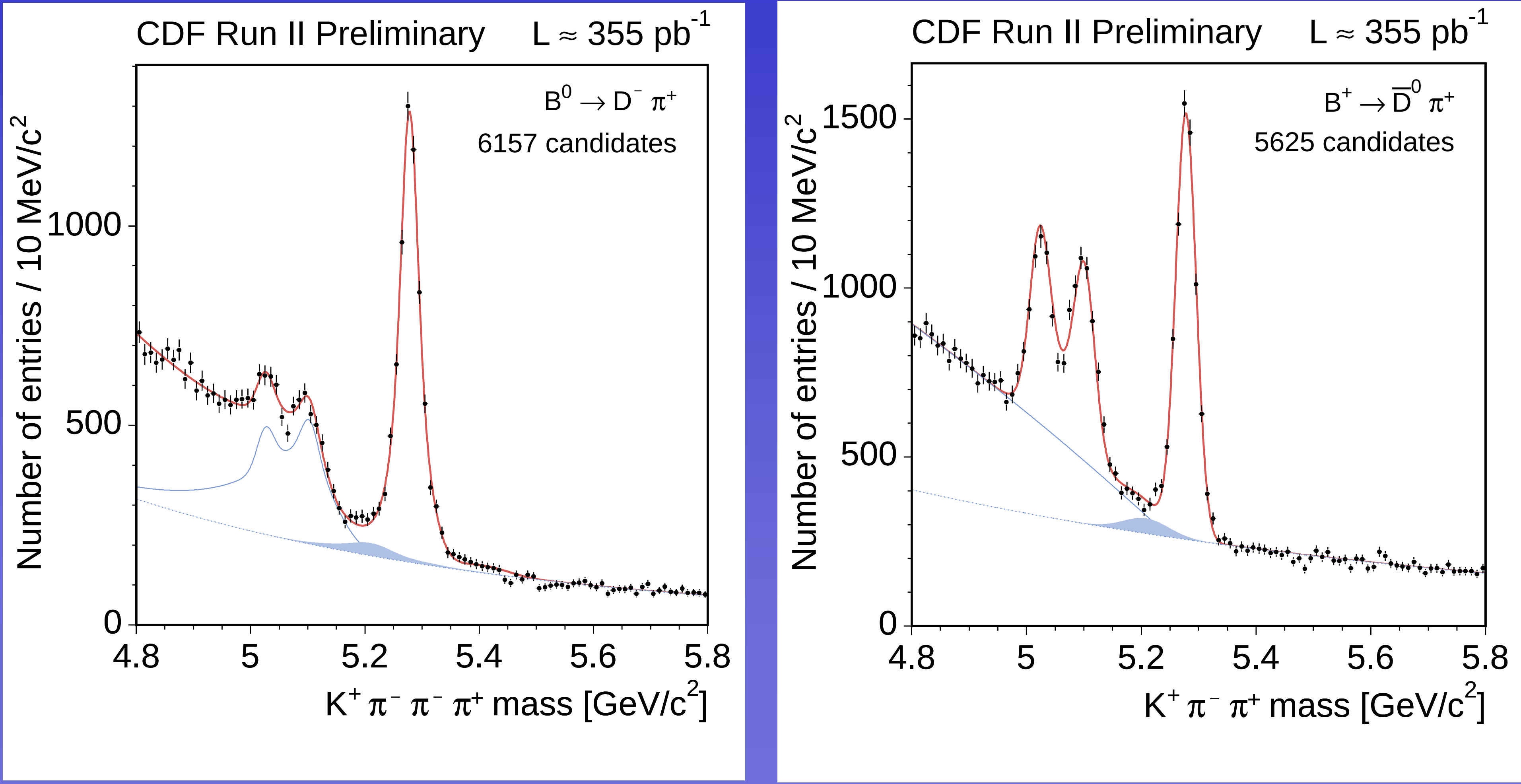


Figure 5: Sensitivity projections for 3σ observation.

Calibration B^0 and B^+ hadronic signals

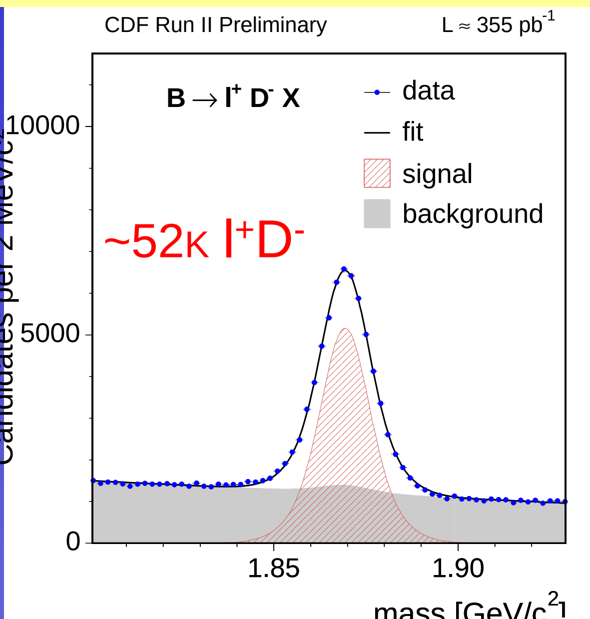
$$B^0 \to D^- \pi^+ (D^- \to K^+ \pi^- \pi^-)$$

$$B^+ \to D^0 \pi^+ (D^0 \to K^+ \pi^-)$$

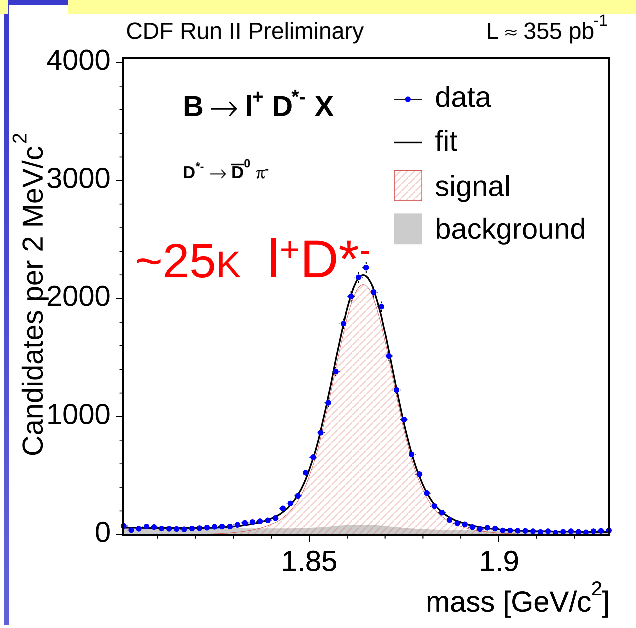


Semileptonic B^0 and B^+ Signals

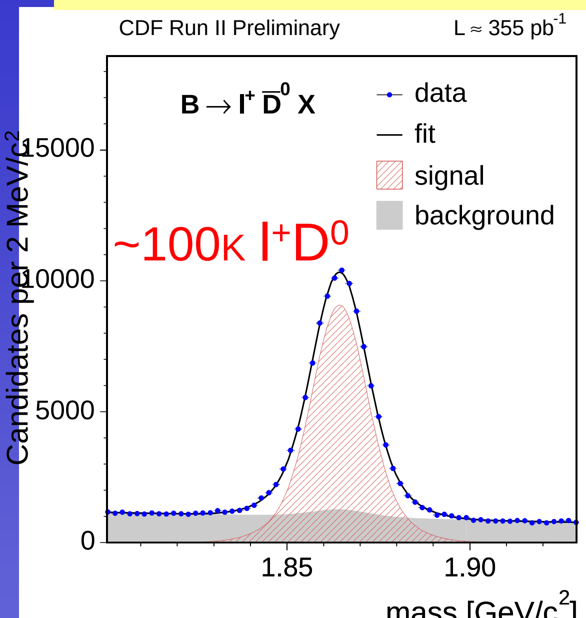
$B \to D^- l^+ \nu X \, (D^- \to K^+ \pi^- \pi^-)$



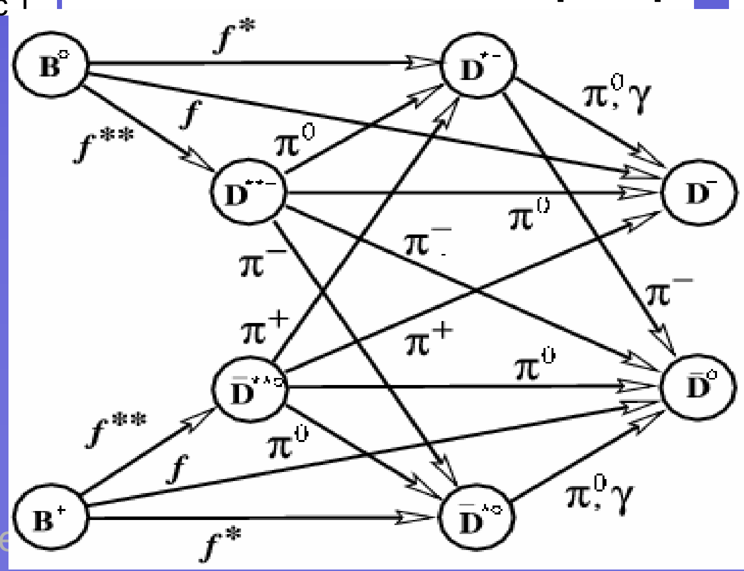
$B \to D^{*-} l^+ \nu X \, (D^{*-} \to D^0 \pi^-)$



$B \to D^0 l^+ \nu X \, (D^0 \to K^+ \pi^-)$

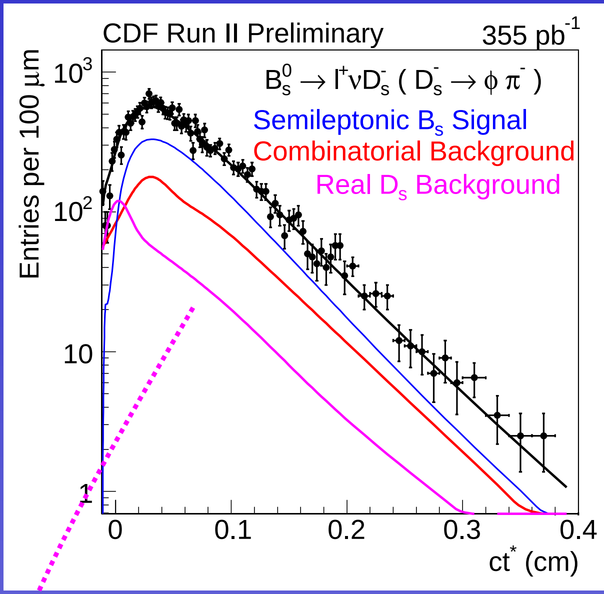


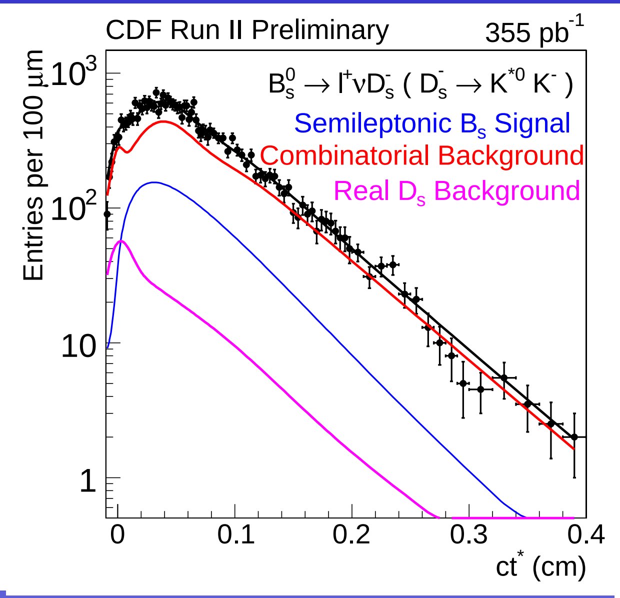
$B^0 \leftrightarrow B^+$ crosstalks:
- $B^0 \to l^+ \nu D^-$
- $B^+ \to l^+ \nu D^{**0}$ with $(D^{**0} \to D^- \pi^+)$

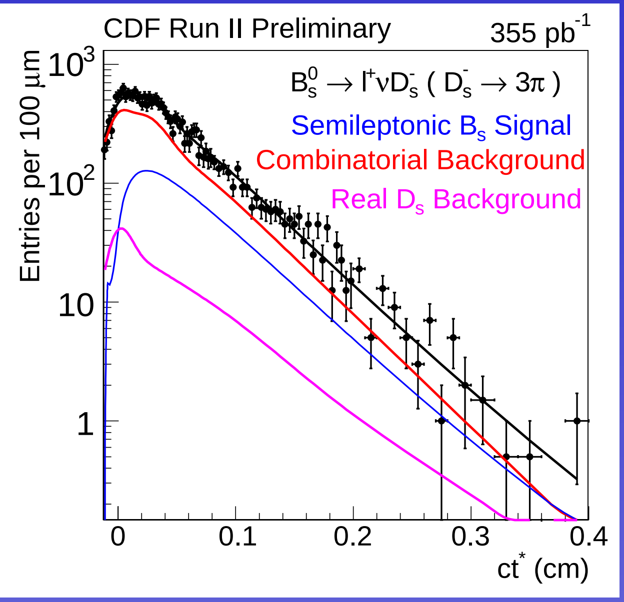


Sample composition
- $\ell + D^+$: $B^0/B^+ \sim 85/15$
- $\ell + D^{*+}$: $B^0/B^+ \sim 85/15$
- $\ell + D^0$: $B^0/B^+ \sim 20/80$

Lifetime in the semileptonic B_s modes







$\tau = 1.521 \pm 0.040$ ps

$c\tau = 413.8 \pm 20.1\ \mu m$

$c\tau = 422.6 \pm 25.7\ \mu m$

Combined ℓ-D_s lifetime result: **$445.0 \pm 9.5\ \mu m$** *(W.A.: $438 \pm 17\ \mu m$)*

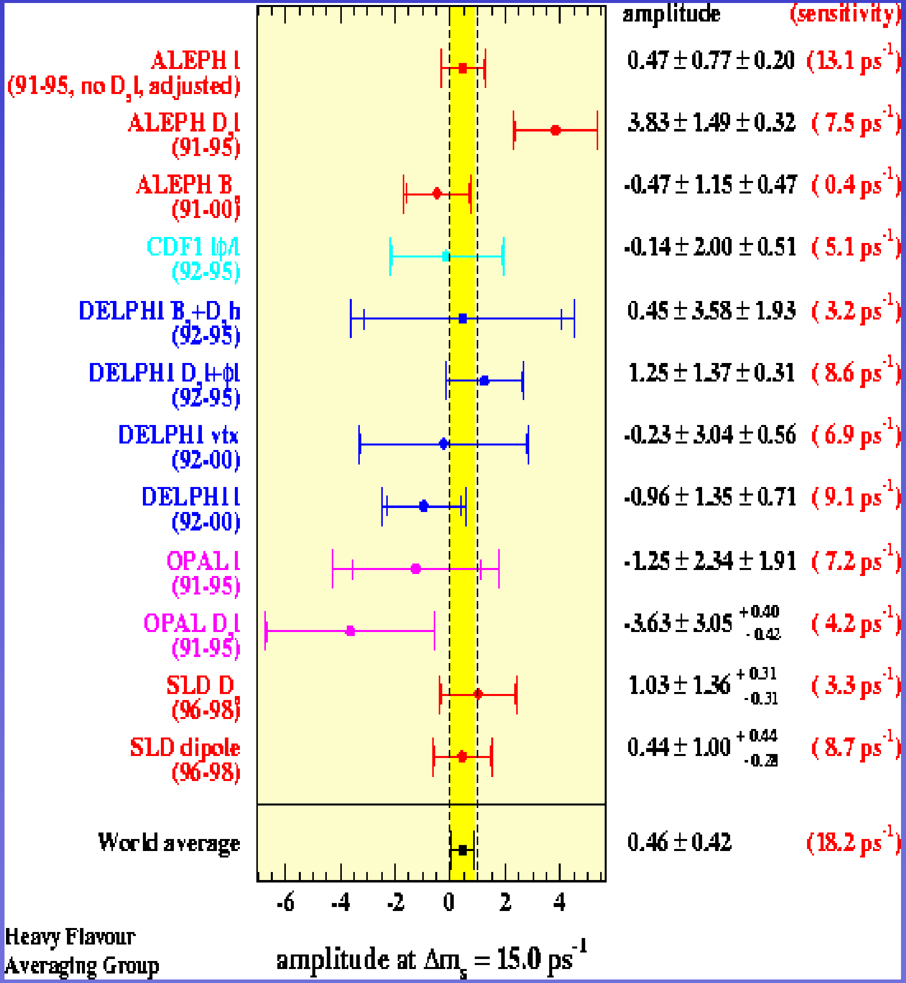
statistical err .only, ***→NOT for Averages←*** *(DØ '05: $426 \pm 13 \pm 17\ \mu m$)*

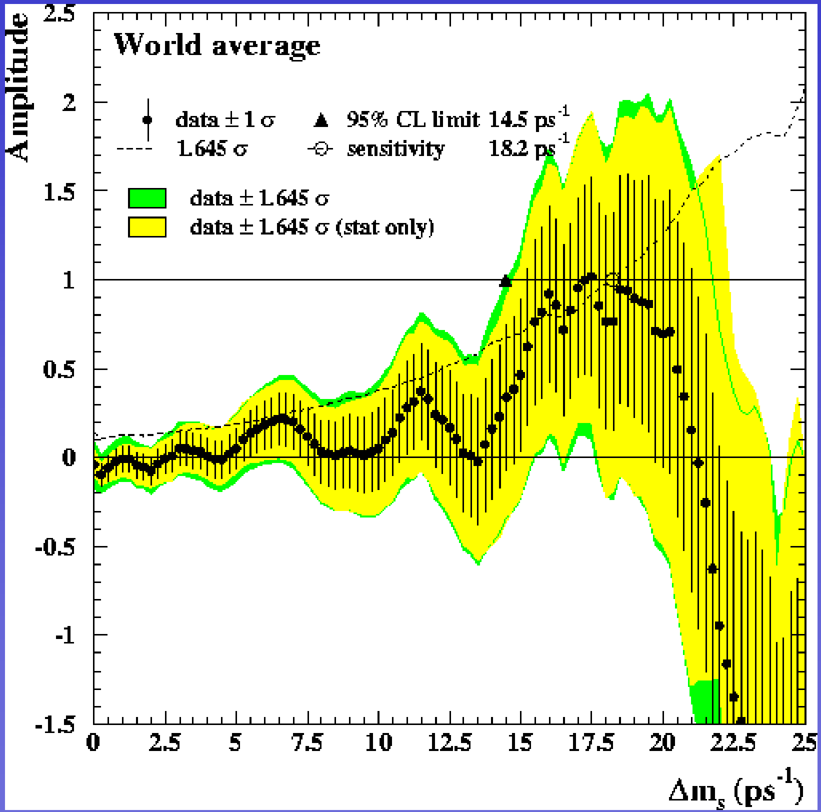
Real D_s backgrounds: prompt and physics

Experimental status on Δm_s

Present limit (HFAG 2004)
from: **LEP / SLD / CDF run I**

Amplitude scan method discussed later

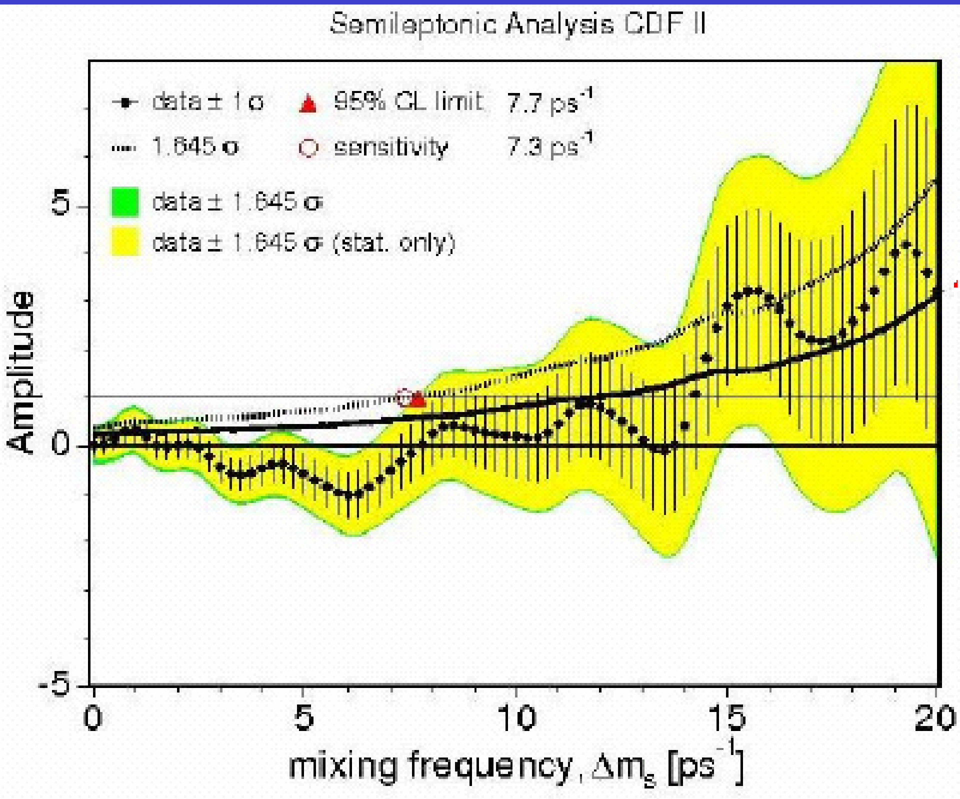


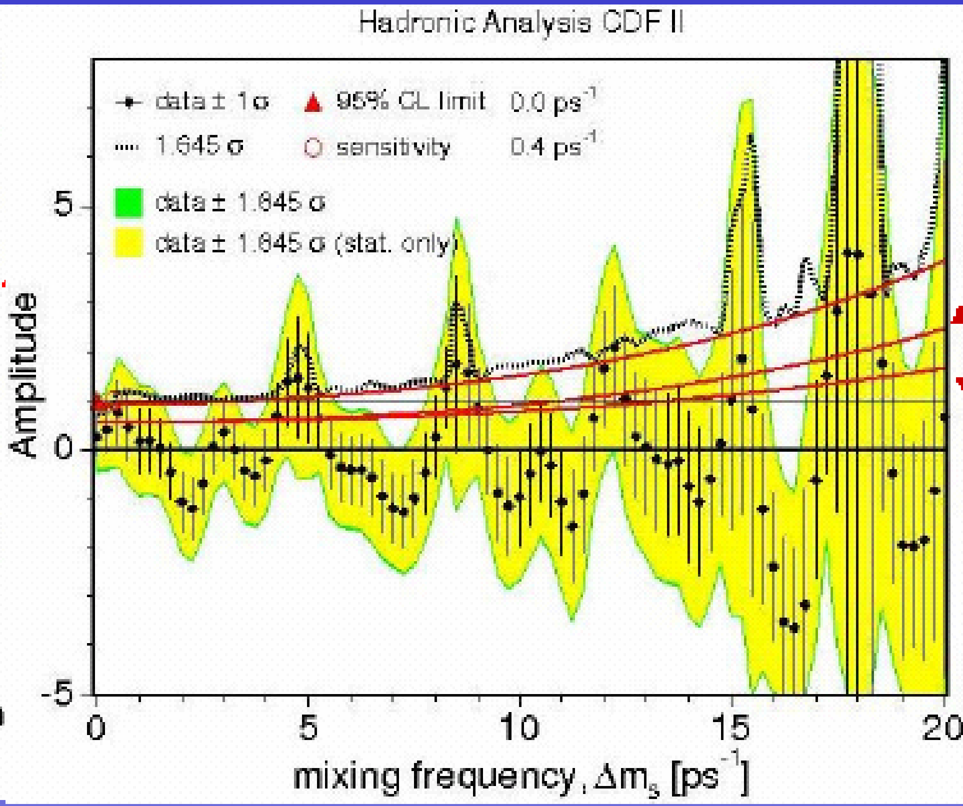


- 95% CL limit is : $\Delta m_s > 14.5$ ps^{-1}
- Sensitivity: 18.2 ps^{-1}

Short term realistic scenario

Increase the actual effective statistics **x4** (i.e. increase **NεD^2** x**4**)

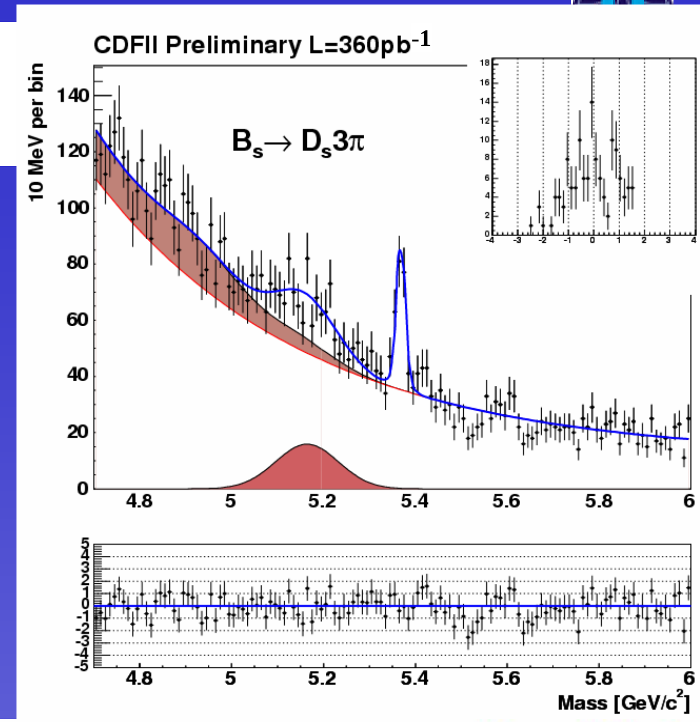


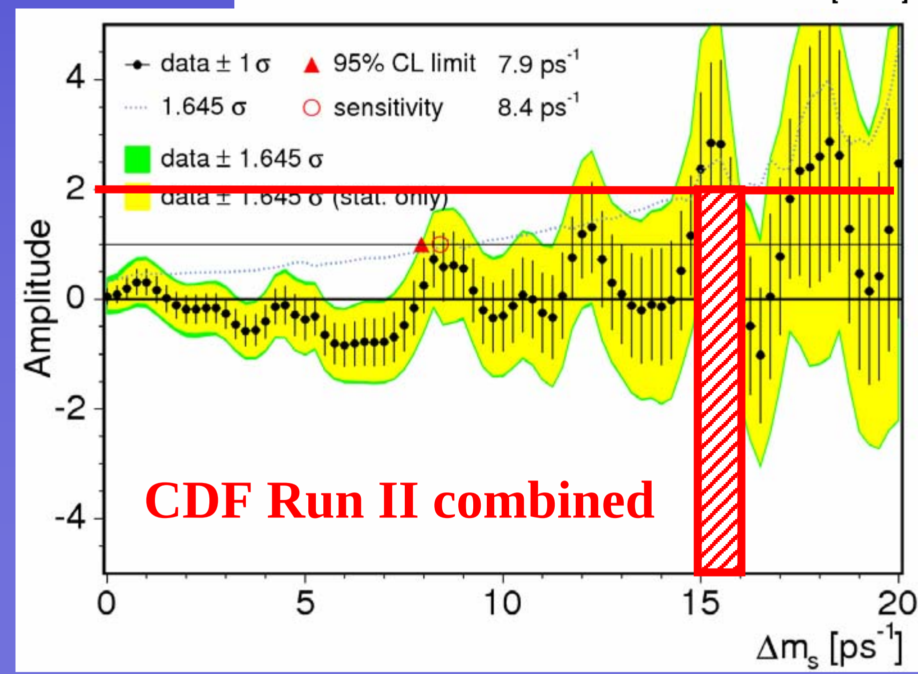


- Hadronic analysis will begin to lead the sensitivity
- Start to “eat” interesting Δm_s range combining the 2 analysis

Mixing Improvements

- Include Same Side (Kaon) Tagging
  - Expect twice tagging power than OST combined
  - x3 statistical power! … but systematics limited in setting a limit
- Improve accuracy of primary vertex
  - \- 20% on $\sigma(ct)$ → +40% on εD^2 @ $\Delta m_s = 10\ ps^{-1}$
- Add more channels +30%
  - $Bs \rightarrow Ds3\pi$
  - $Bs \rightarrow Ds^*\pi$, $Bs \rightarrow Ds\rho^+$
- x4 statistical power feasible with same data set → x2 on amplitude error





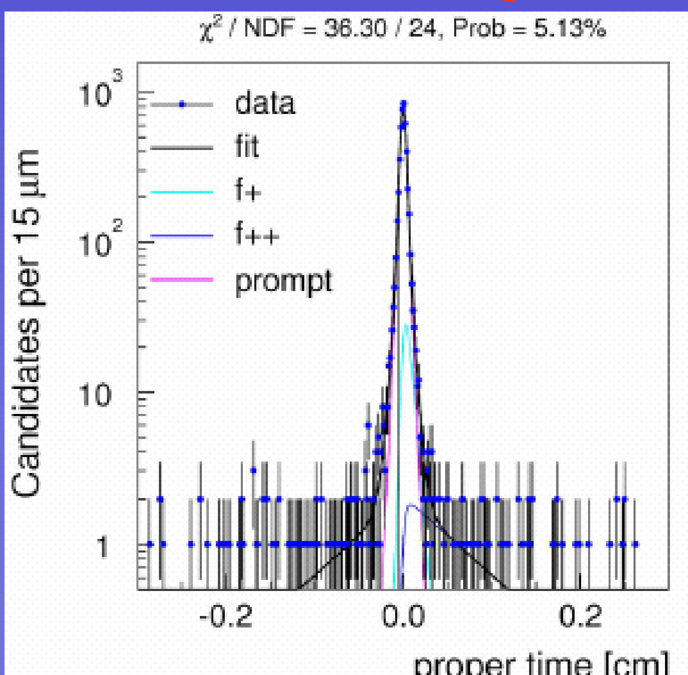
Decay Time Resolution

Decay vertex error matrix overall correction for mis-knowledge of hit resolution

→ Apply a scale factor S to $\sigma(ct)$ from vertex fit:

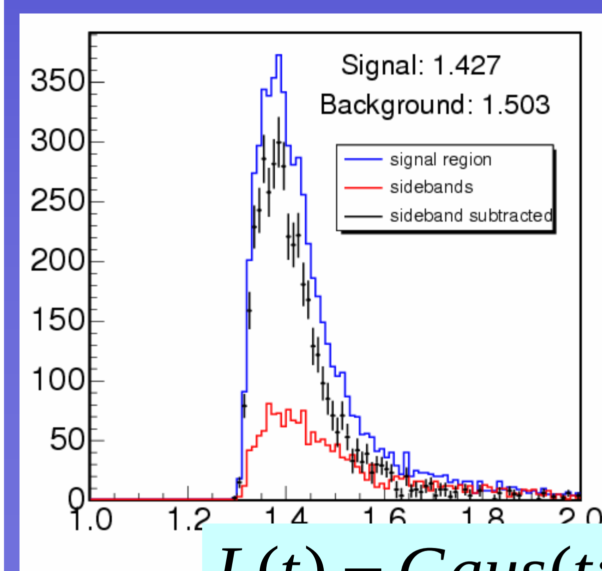
- Huge control sample: $D_s^{\pm}$ + random track to emulate B_s decay topology
- Correct for small (10%) secondary $D_s^{\pm}$ in the sample
- Parameterize S in terms of several variables (P_T, Isolation,…)
- Correct $\sigma(ct)' = S \cdot \sigma(ct)$ event by event.

Prompt track + D_s vertex



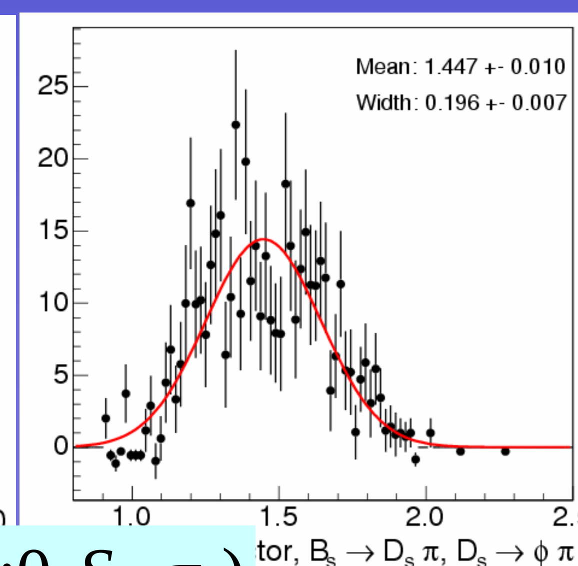
"Semileptonic" B_s signal

$B_s^0 \to D_s^- l^+ \nu X \,(D_S^- \to \phi\pi^-)$



"Hadronic" B_s signal

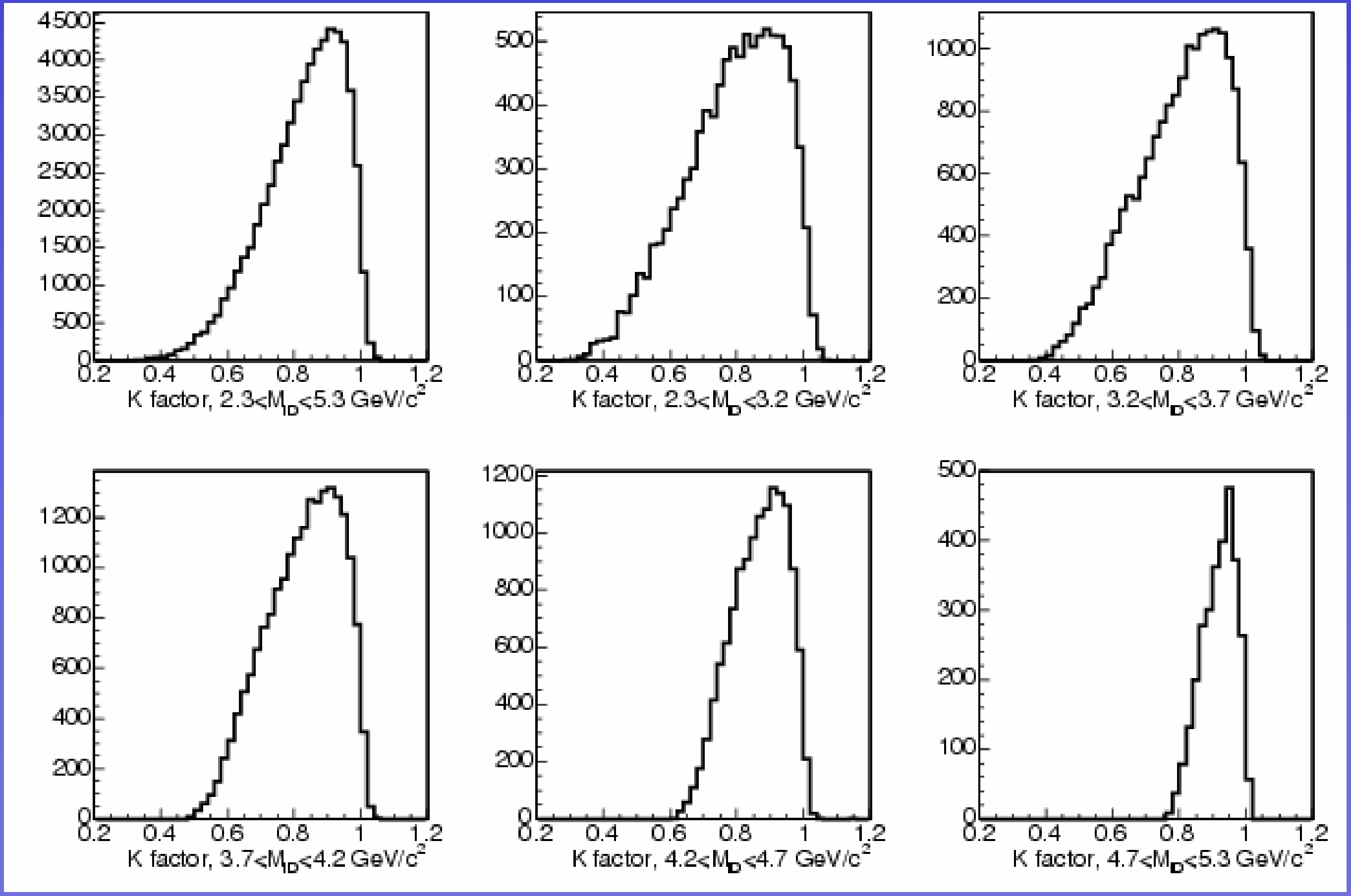
$B_s^0 \to D_s^- \pi^+ \,(D_S^- \to \phi\pi^-)$



$$L(t) = Gaus(t; 0, S \cdot \sigma_t)$$

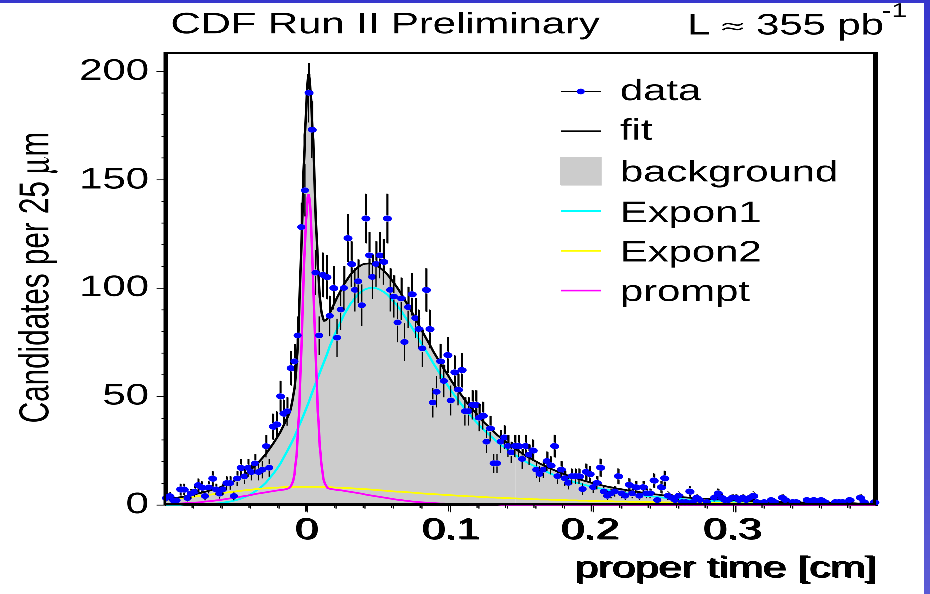
M(ID) Binning for K factor

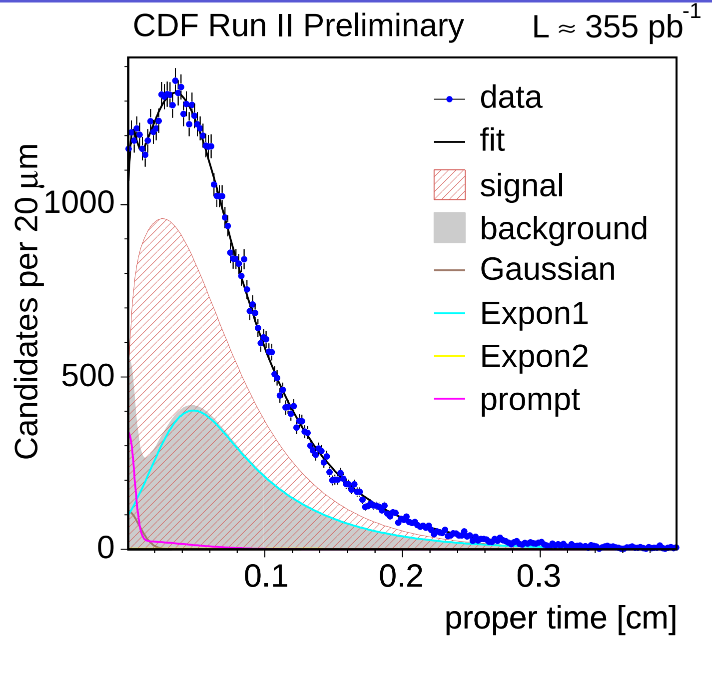
- Resolution of K factor:
  - better for high M(ID)
  - Dividing event in different M(ID)
- Evaluate K factor in each M(ID) bin
  - Improve the decay time resolution

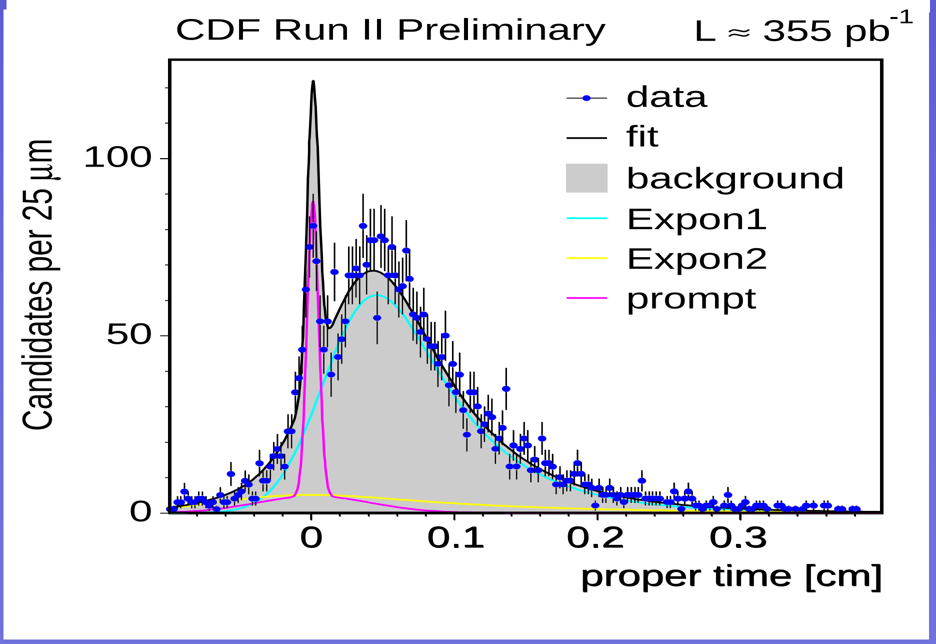


Prompt Background

- Clear prompt peak also in the right sign lepton + D+ events
- Event tagged with high dilution tagger (Muon, Electron, Vertex)
  - Prompt background is reduced
  - No opposite side B for prompt BG

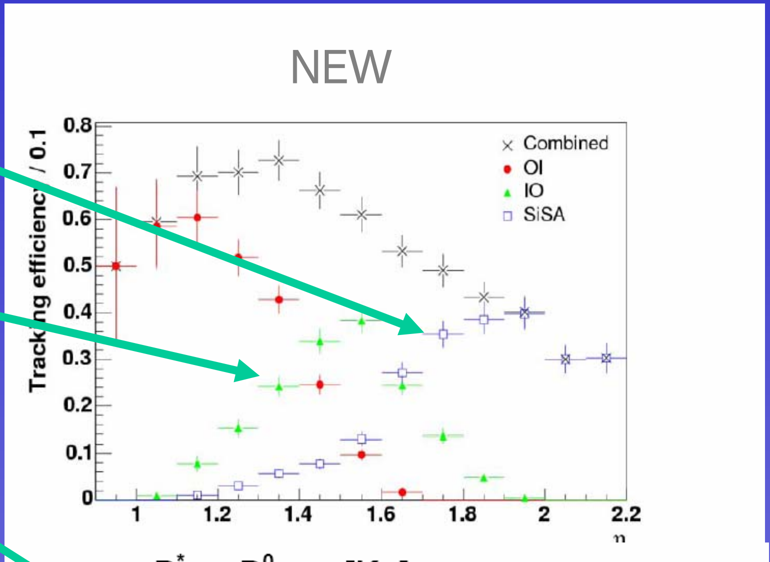


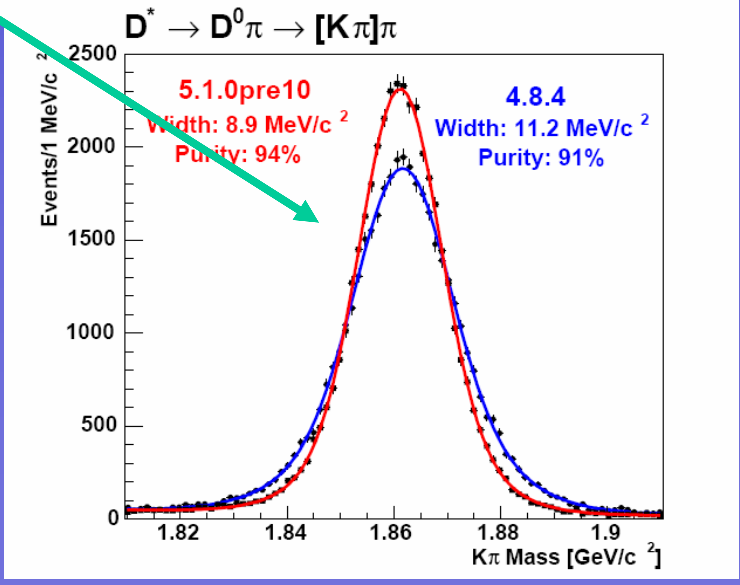


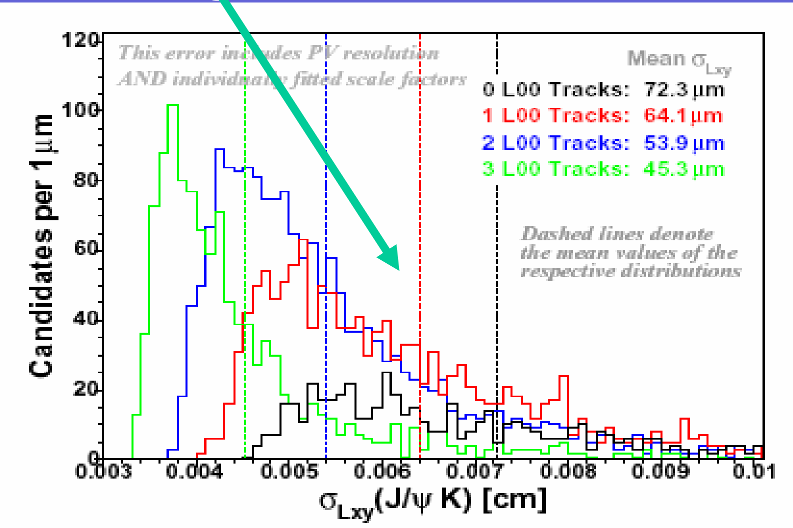


Tracking

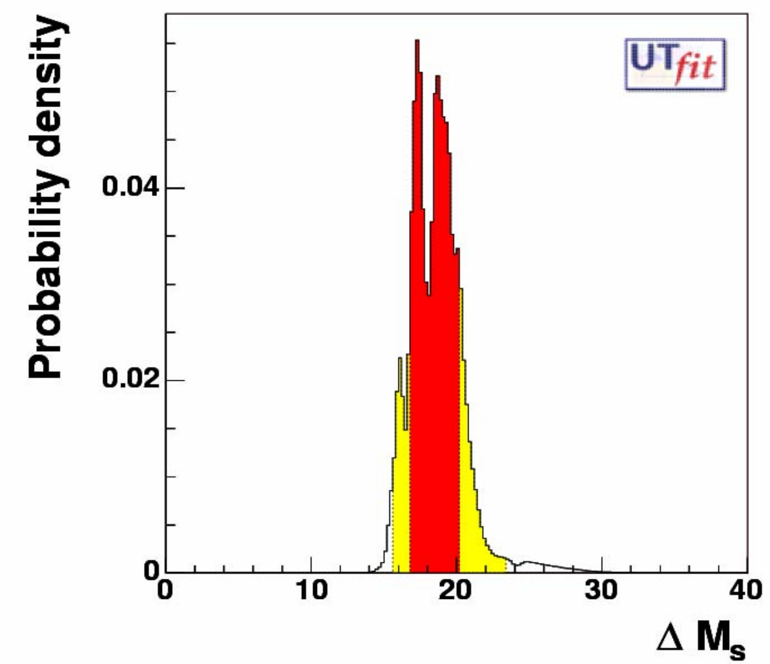
- Great progress in Si stand-alone
- Substantial efficiency improvement at large η and low-pt
- Improved mass resolution
- L00 now ready for physics:
  - eff. 60% and growing
  - Clear improvement in $\sigma(L_{xy})$,crucial for Bs mixing





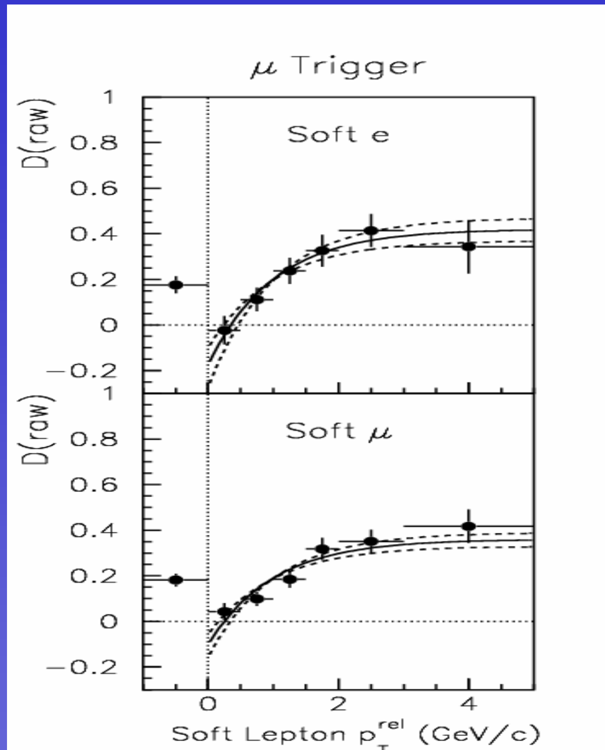


- Strange peaks in expected Dms being there already before Tevatron new input



Flavor tagging – Soft Leptons

Run I



Run II

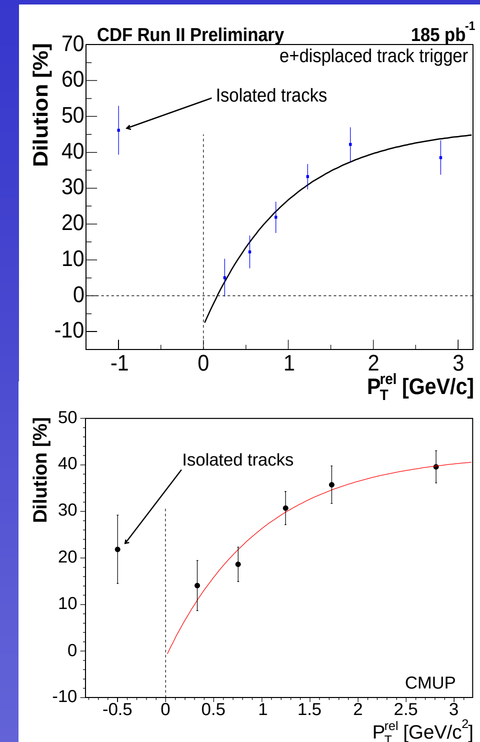


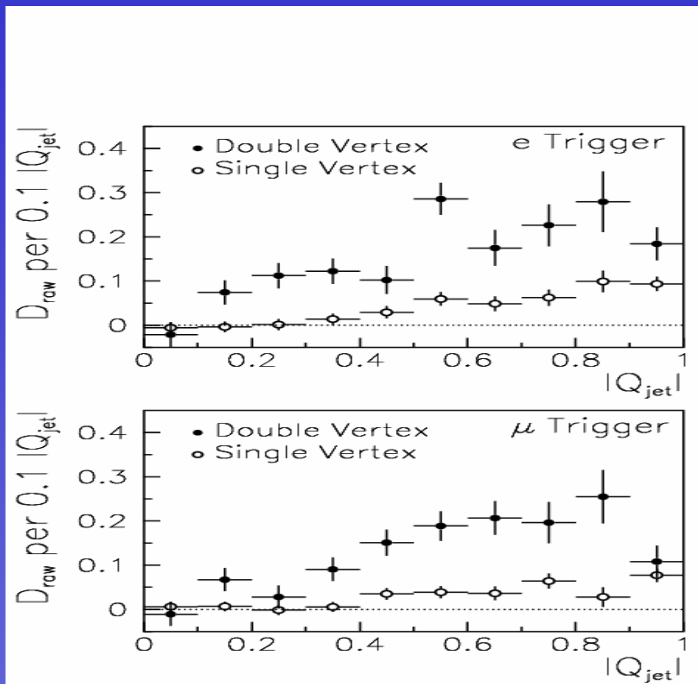
TABLE X. The statistical power ϵD^2 for the flavor tagging methods used: Jet-Charge Single Vertex (JCSV), Jet-Charge Double Vertex (JCDV), and Soft-Lepton Tag (SLT). Results for the e and μ trigger data are shown in separate rows. The sum is over bins of $p_T^{\rm rel}$ for the soft-lepton data and $|Q_{\rm jet}|$ for the jet-charge data, as shown in Figures 7 and 9, respectively. The square of the dilution normalization factor N_D is used to rescale the $\sum_i \epsilon_i D^2_{{\rm raw}\ i}$ value to give $\sum_i \epsilon_i D_i^2$. The first error is statistical, the second systematic.

Sample	Total ϵ	$\sum_i \epsilon_i D^2_{{\rm raw}\ i}$	N_D	$\sum_i \epsilon_i D_i^2$
JCSV (e)	41.55 ± 0.14 %	0.077 ± 0.016 %	1.88 ± 0.20 ± 0.15	0.27 ± 0.06 ± 0.04 %
JCDV (e)	7.44 ± 0.08 %	0.159 ± 0.023 %	1.76 ± 0.13 ± 0.09	0.49 ± 0.10 ± 0.05 %
SLT (e)	4.38 ± 0.06 %	0.329 ± 0.033 %	1.72 ± 0.08 ± 0.11	0.97 ± 0.13 ± 0.12 %
JCSV (μ)	43.81 ± 0.14 %	0.048 ± 0.012 %	2.41 ± 0.29 ± 0.39	0.28 ± 0.06 ± 0.05 %
JCDV (μ)	7.66 ± 0.07 %	0.113 ± 0.018 %	2.14 ± 0.33 ± 0.25	0.52 ± 0.18 ± 0.12 %
SLT (μ)	4.54 ± 0.06 %	0.210 ± 0.026 %	2.01 ± 0.13 ± 0.22	0.85 ± 0.15 ± 0.19 %

	εD^2 (%)
Muon	(0.70±0.04)%
Electron	(0.37±0.03)%
	(0.36±0.02)%
	(0.36±0.03)%
	(0.15±0.01)%
	~1.6%

Flavor tagging – Jet Charge

Run I



Run II

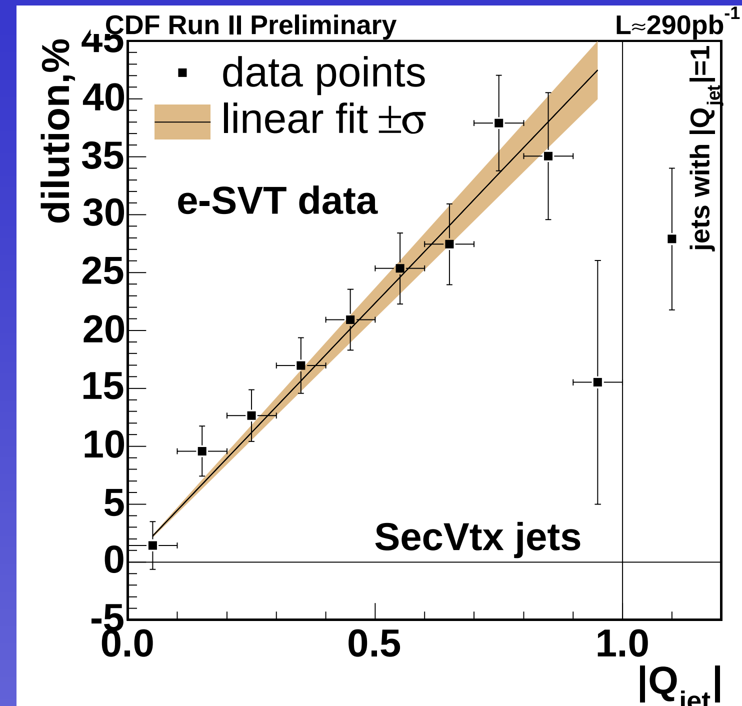


TABLE X. The statistical power ϵD^2 for the flavor tagging methods used: Jet-Charge Single Vertex (JCSV), Jet-Charge Double Vertex (JCDV), and Soft-Lepton Tag (SLT). Results for the e and μ trigger data are shown in separate rows. The sum is over bins of p_T^{rel} for the soft-lepton data and $|Q_{jet}|$ for the jet-charge data, as shown in Figures 7 and 9, respectively. The square of the dilution normalization factor N_D is used to rescale the $\sum_i \epsilon_i D^2_{raw\ i}$ value to give $\sum_i \epsilon_i D^2_i$. The first error is statistical, the second systematic.

Sample	Total ϵ	$\sum_i \epsilon_i D^2_{raw\ i}$	N_D	$\sum_i \epsilon_i D^2_i$
JCSV (e)	41.55 ± 0.14 %	0.077 ± 0.016 %	1.88 ± 0.20 ± 0.15	0.27 ± 0.06 ± 0.04 %
JCDV (e)	7.44 ± 0.08 %	0.159 ± 0.023 %	1.76 ± 0.13 ± 0.09	0.49 ± 0.10 ± 0.05 %
SLT (e)	4.38 ± 0.06 %	0.329 ± 0.033 %	1.72 ± 0.08 ± 0.11	0.97 ± 0.13 ± 0.12 %
JCSV (μ)	43.81 ± 0.14 %	0.048 ± 0.012 %	2.41 ± 0.29 ± 0.39	0.28 ± 0.06 ± 0.05 %
JCDV (μ)	7.66 ± 0.07 %	0.113 ± 0.018 %	2.14 ± 0.33 ± 0.25	0.52 ± 0.18 ± 0.12 %
SLT (μ)	4.54 ± 0.06 %	0.210 ± 0.026 %	2.01 ± 0.13 ± 0.22	0.85 ± 0.15 ± 0.19 %

	εD^2 (%)
	(0.70±0.04)%
	(0.37±0.03)%
2ndary vtx	(0.36±0.02)%
Displaced track	(0.36±0.03)%
Highest p jet	(0.15±0.01)%
	~1.6%