Measurements of B_s Oscillations at the Tevatron

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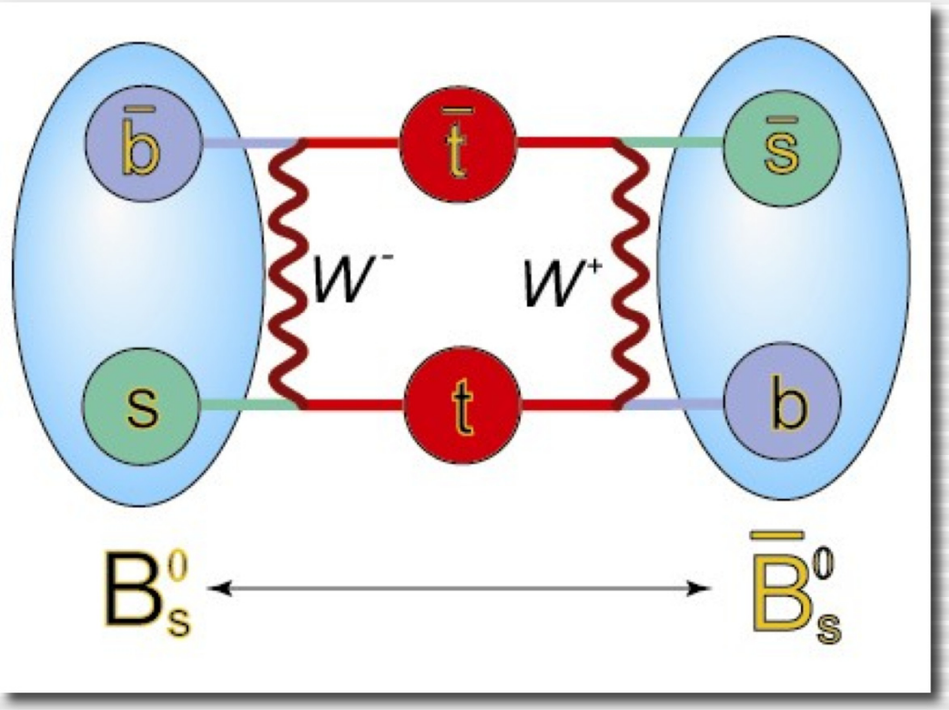
On behalf of the CDF and DØ collaborations

- Motivation
- Accelerator & Detectors
- B_s Oscillation Results
- Conclusion



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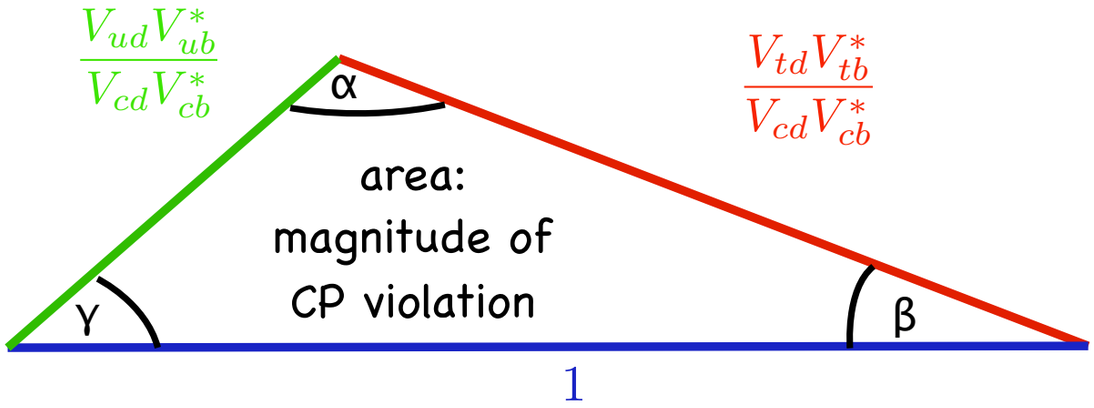
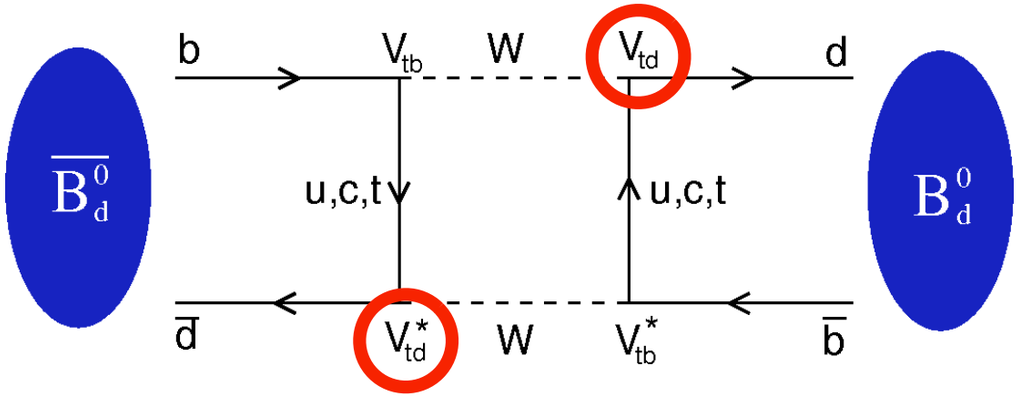
CKM Matrix

- visualization of unitary matrix through 1 of 6 unitarity triangles



- check consistency of SM through over-constraining of sides and angles of unitarity triangle:
  - angles: CP violating processes
  - sides: CP conserving processes



two mass eigenstates with mass difference

$\Delta m = m_H - m_L \approx |M_{12}|$

⇒ oscillation of B-mesons

- deviation from theoretical predictions
  - indication for new physics

→ probes magnitude of new physics in loops through $|M_{12}|$ and constraints phase ϕ_s

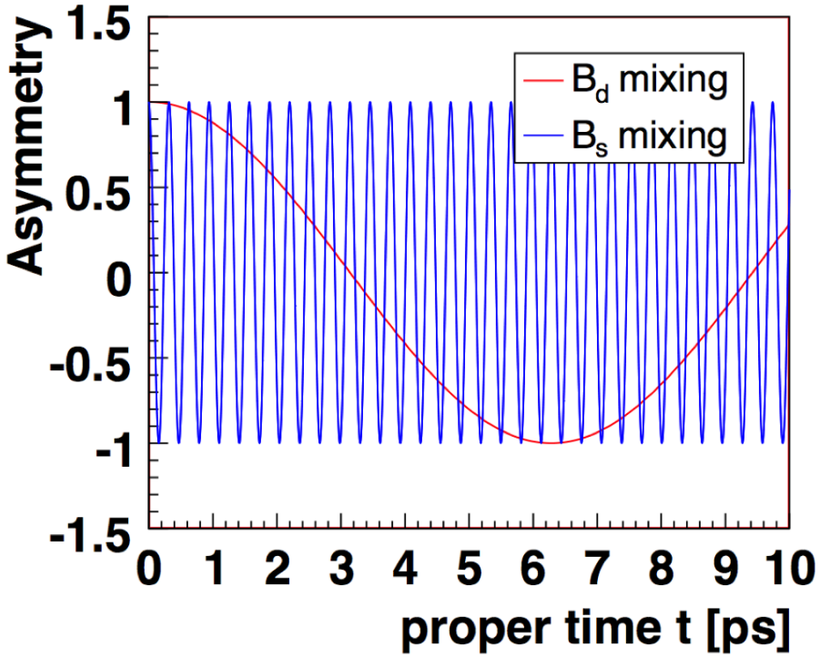
$\Delta\Gamma_s = \Gamma_L - \Gamma_H = \Delta\Gamma_{CP}\cos\phi_s$

$\Delta\Gamma_{CP} = \Gamma_{even} - \Gamma_{odd} \approx 2|\Gamma_{12}|$

B Meson Mixing

$$\Delta m_d \propto m_{B_d^0} F\left(\frac{m_t^2}{m_W^2}\right) \eta_{QCD} B_{B_d^0} f_{B_d^0}^2 |V_{tb}^* V_{td}|^2 \qquad \mathcal{O}(20\%)$$ hadronic uncertainties

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s^0}}{m_{B_d^0}} \xi^2 \frac{|V_{ts}^2|}{|V_{td}^2|}, \quad \xi^2 = (1.210^{+0.047}_{-0.035})^2 \qquad \mathcal{O}(4\%)$$ (LQCD Okamoto, Lat2005)



$$A(t) = \frac{N_{unosc}(t) - N_{osc}(t)}{N_{unosc}(t) + N_{osc}(t)} \propto \cos(\Delta m \cdot t)$$

B_s: oscillation much faster

→ experimental challenge: high boost + good time resolution

Measurement

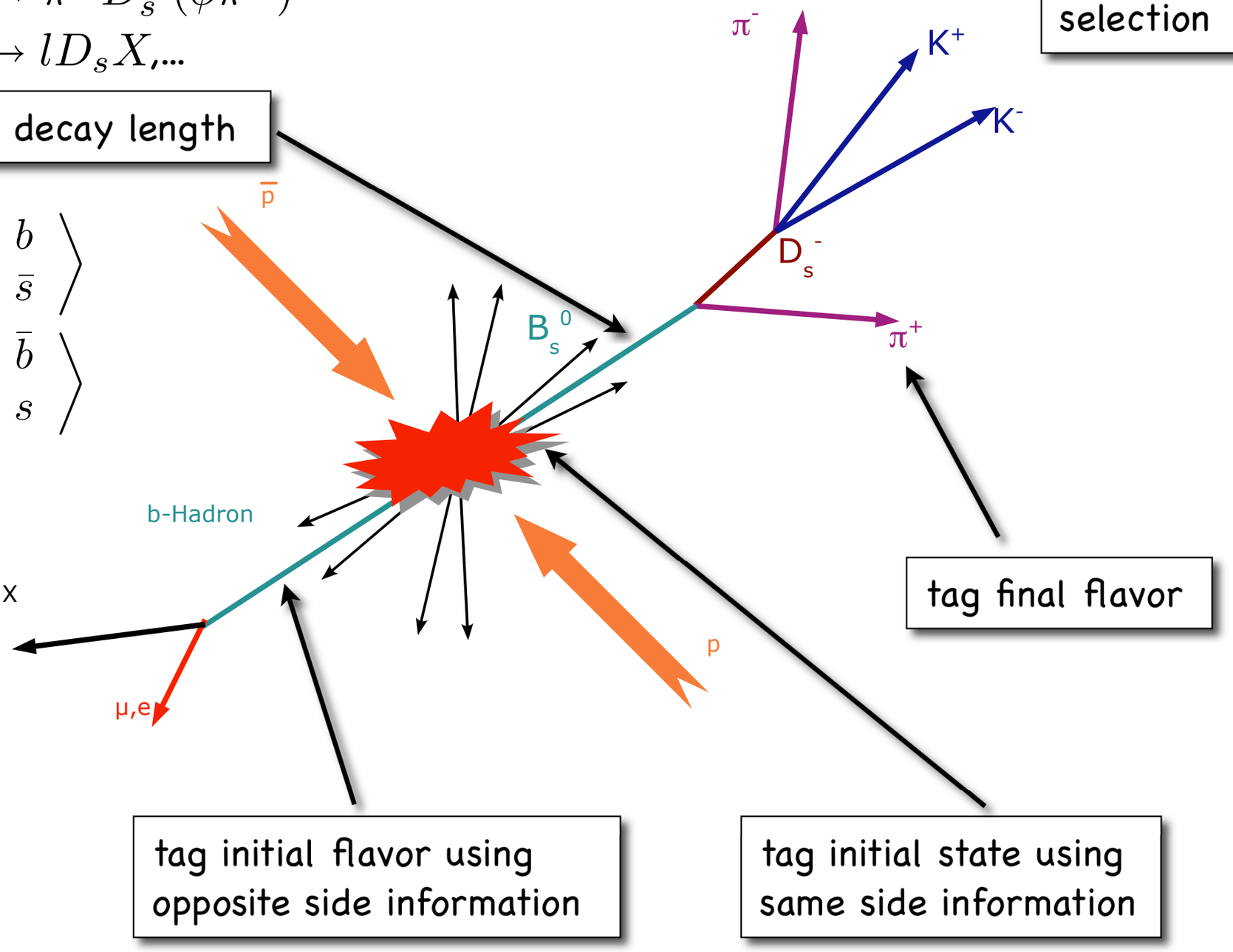
example: $B_s^0 \to \pi^+ D_s^- (\phi\pi^-)$

also: $B_s^0 \to l D_s X$,...

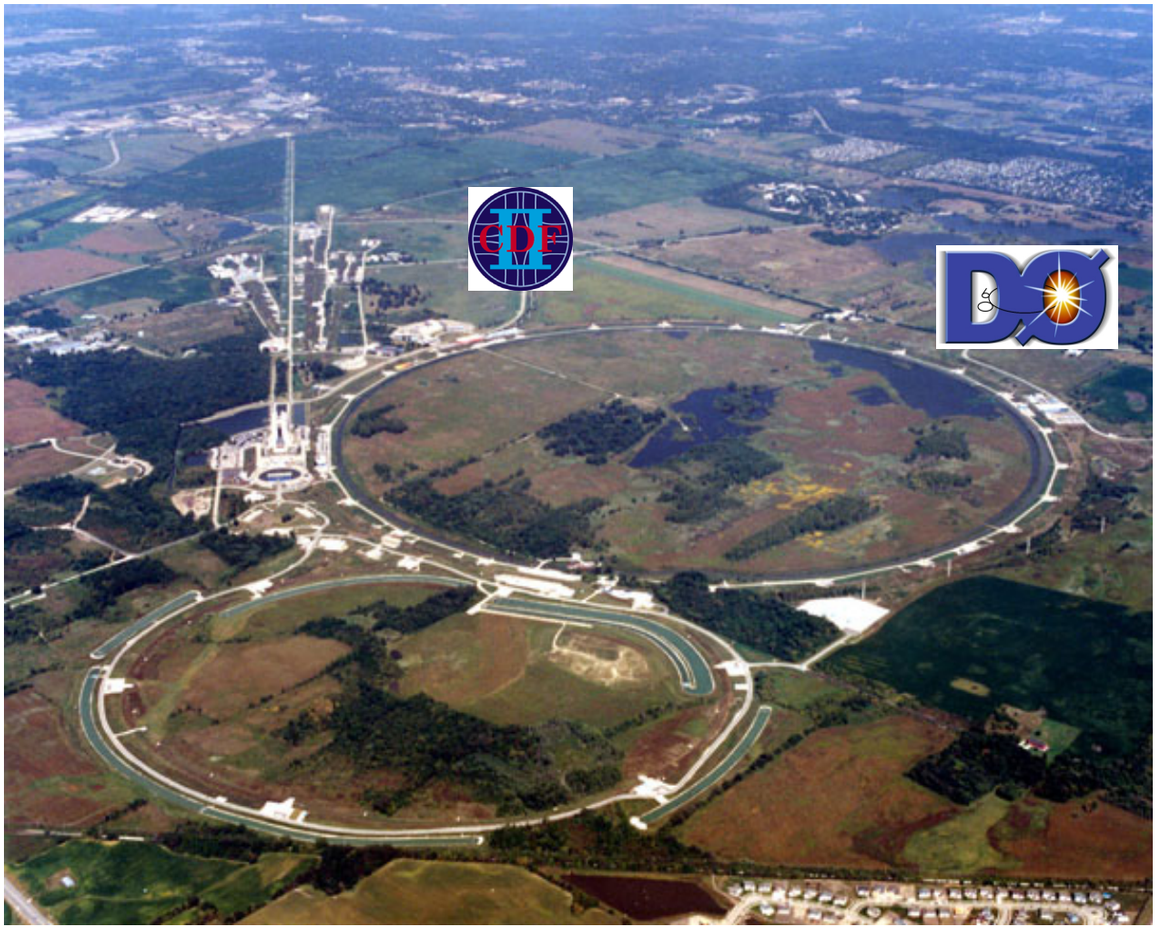
measure B_s decay length

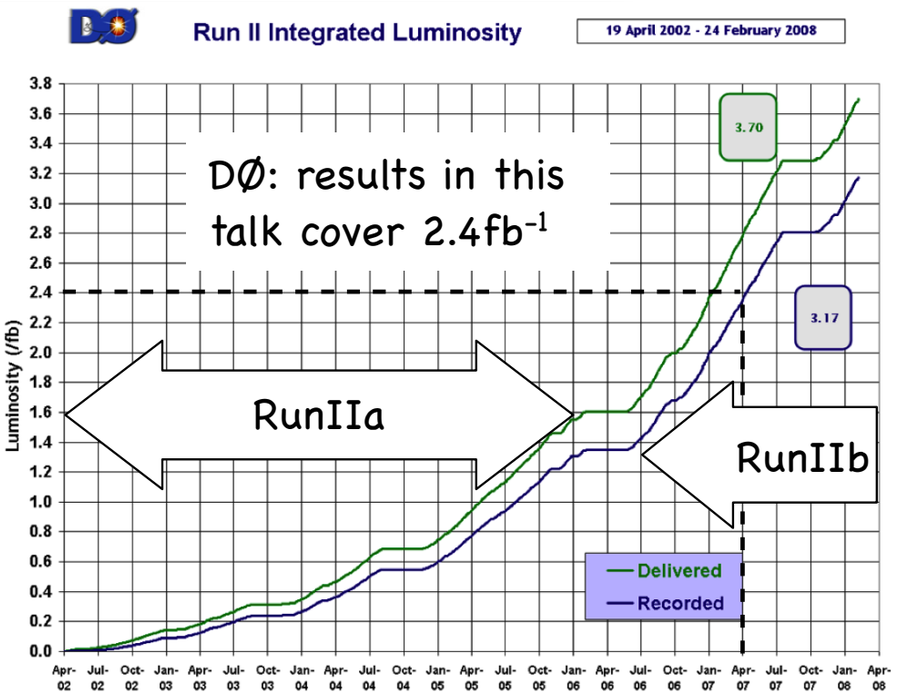
$$\bar{B}_s^0 = \left| \begin{matrix} b \\ \bar{s} \end{matrix} \right\rangle$$

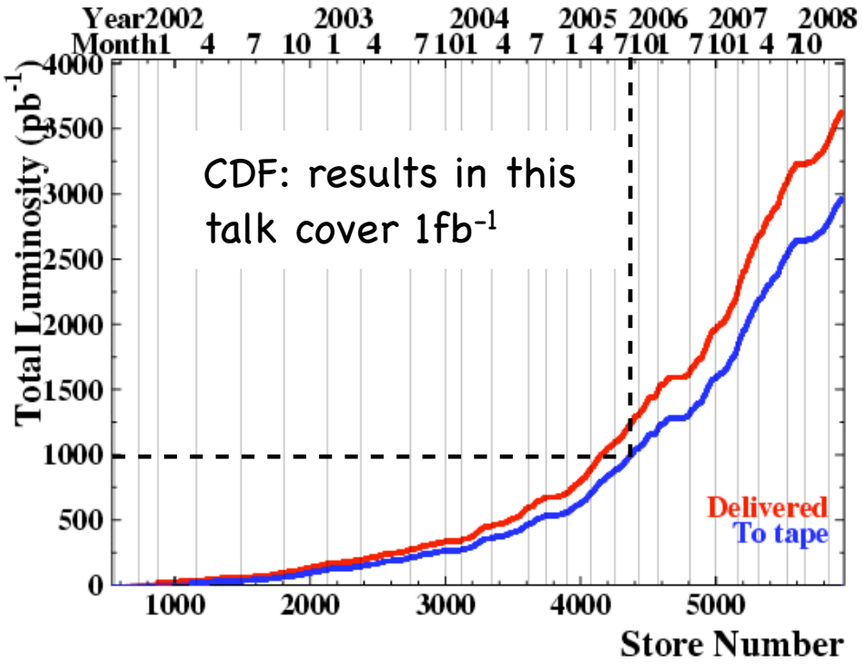
$$B_s^0 = \left| \begin{matrix} \bar{b} \\ s \end{matrix} \right\rangle$$



Tevatron



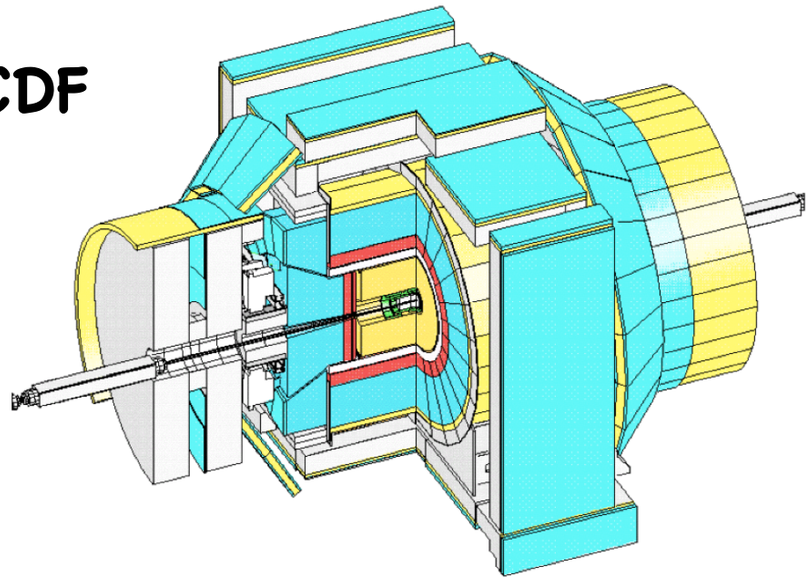




- $p\bar{p}$ collisions @ $\sqrt{s}$ = 1.96 TeV
- Inst. luminosity record: $280 \cdot 10^{30}$ cm^{-2}s^{-1}
- Integrated luminosity (recorded):
  ≈ 3 fb^{-1} each experiment
- Currently the only place to study B_s-mixing

CDF & DØ Detector

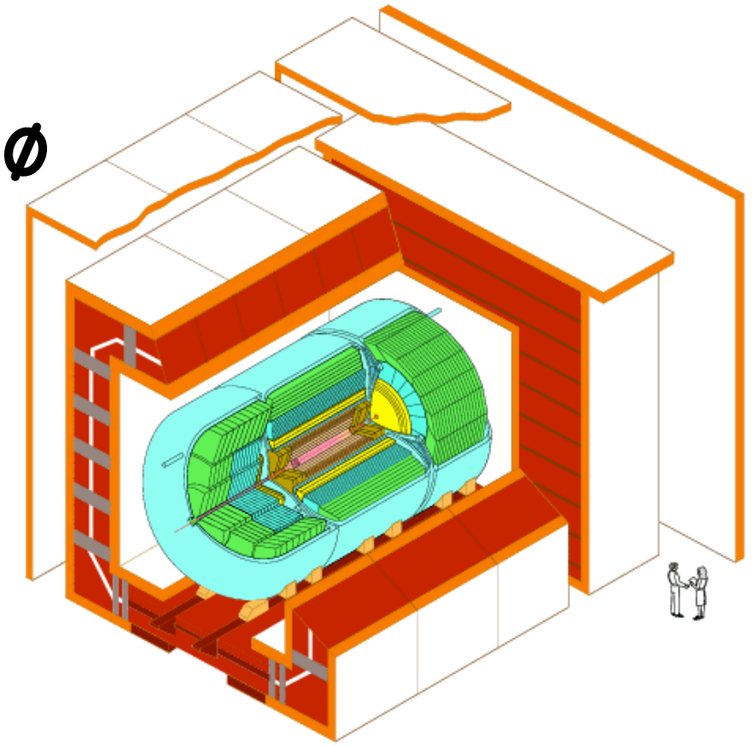
CDF



- lower muon acceptance:
  $|\eta| < 1$
- superior tracking system
  - better momentum/vertex resolution than DØ
- two track trigger at Level-1
- particle ID at trigger level
- large trigger bandwidth at Level-1:
  40kHz compared to 2kHz at DØ

→ **collect large samples of hadronic modes**

DØ

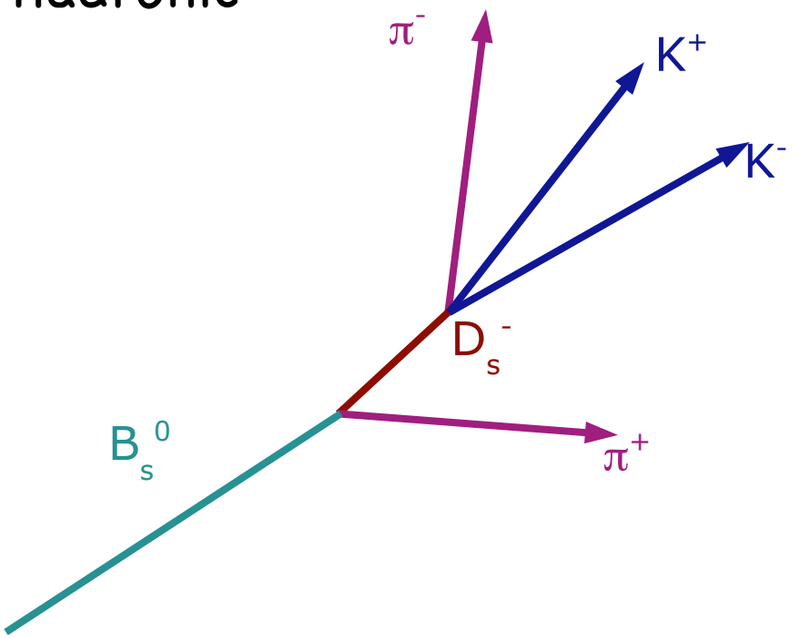


- higher muon acceptance:
  $|\eta| < 2$
- no limitation to single-μ-trigger, while CDF tends to use IP information
- Layer0 since August 2006 (RunIIb)
- trigger: B_s-candidates only through muons
  → all hadronic B_s-candidates are tagged

→ **collect large samples of decays with leptons**

Decay Channels

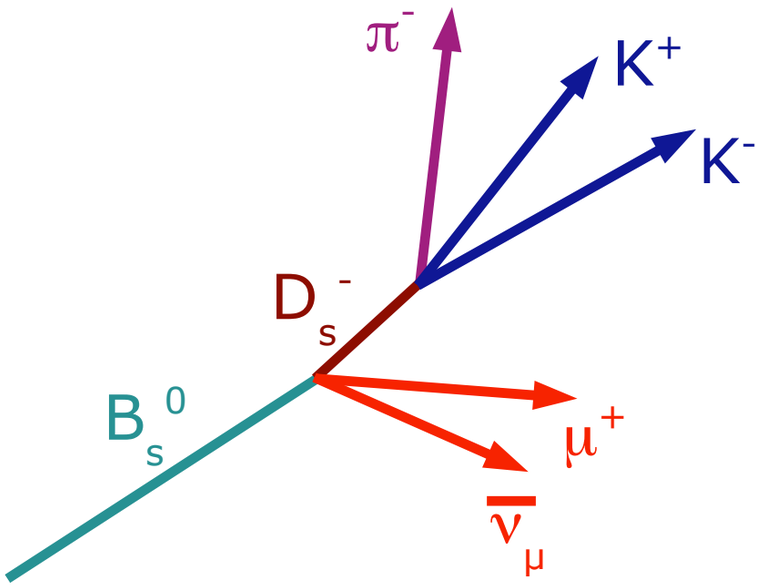
hadronic



- all decay particles reconstructable
  → better time resolution
- low event rate
- higher combinatoric

more sensitive at higher Δm_s

semileptonic

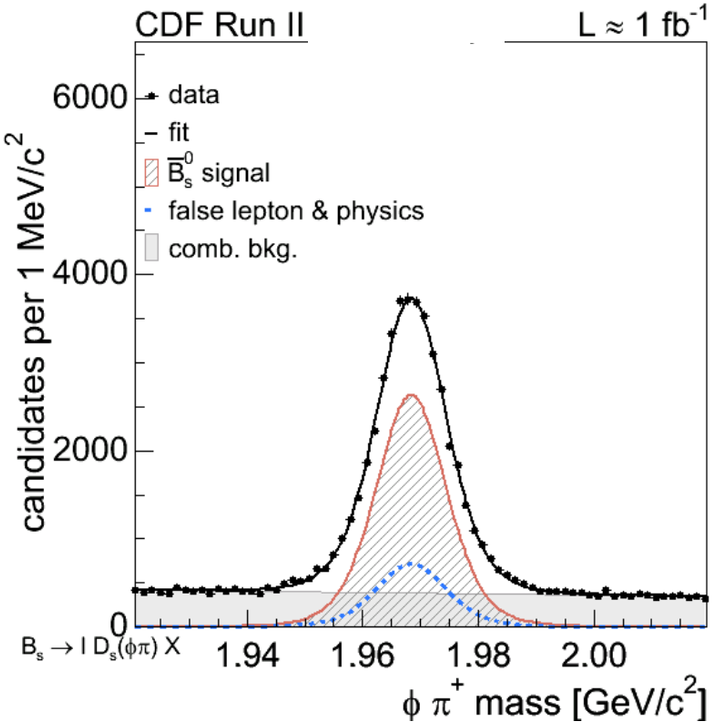


- high event rate
- ν_μ momentum not measurable
  → sensitivity to proper time limited by momentum measurement

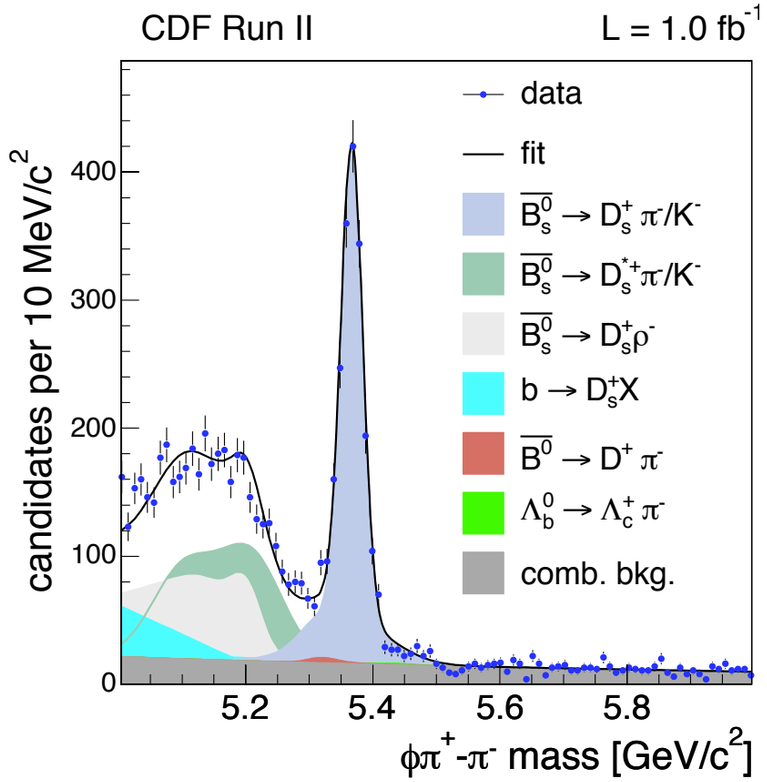
more sensitive at lower Δm_s

Signal Selection (CDF)

$\bar{B}_s \to \mu^- D_s^+ (\phi\pi^+) X$



$\bar{B}_s \to \pi^- D_s^+ (\phi\pi^+)$



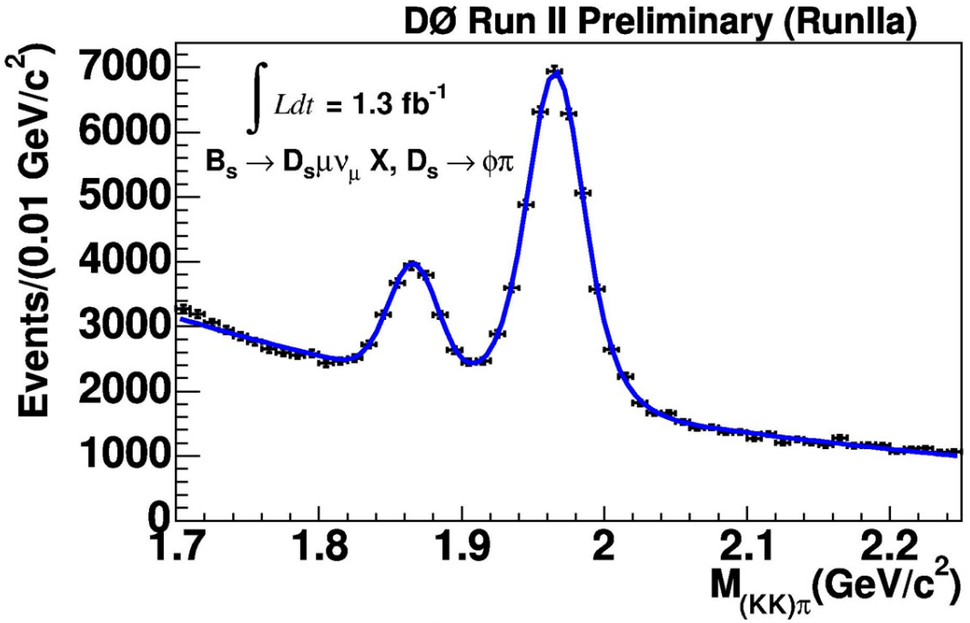
artificial neural network for candidate selection in hadronic modes

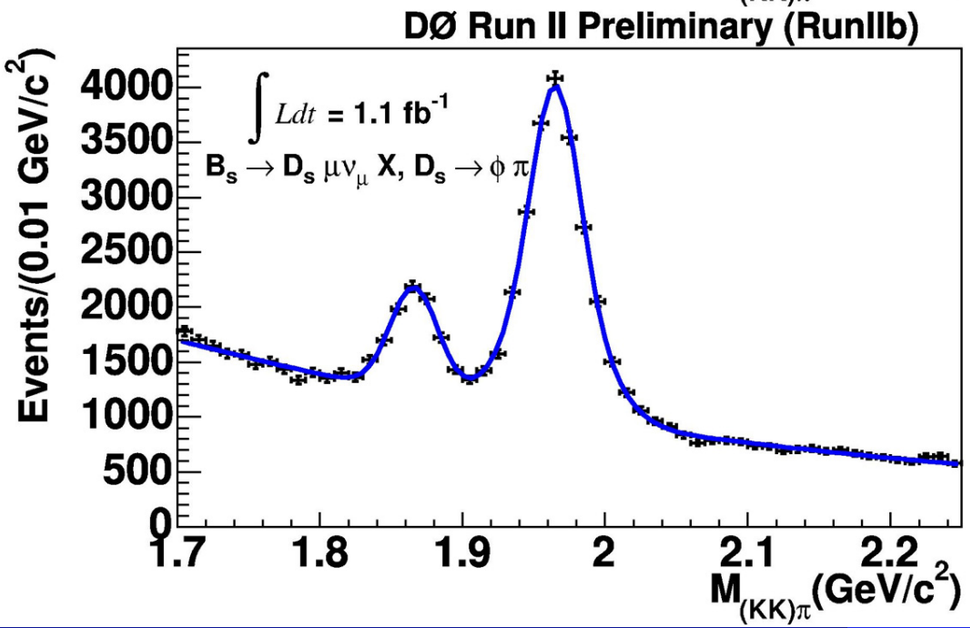
5600 fully reconstructed hadronic events
3100 partially reconstructed hadronic events
61500 partially reconstructed semileptonic events

Signal Selection (DØ)

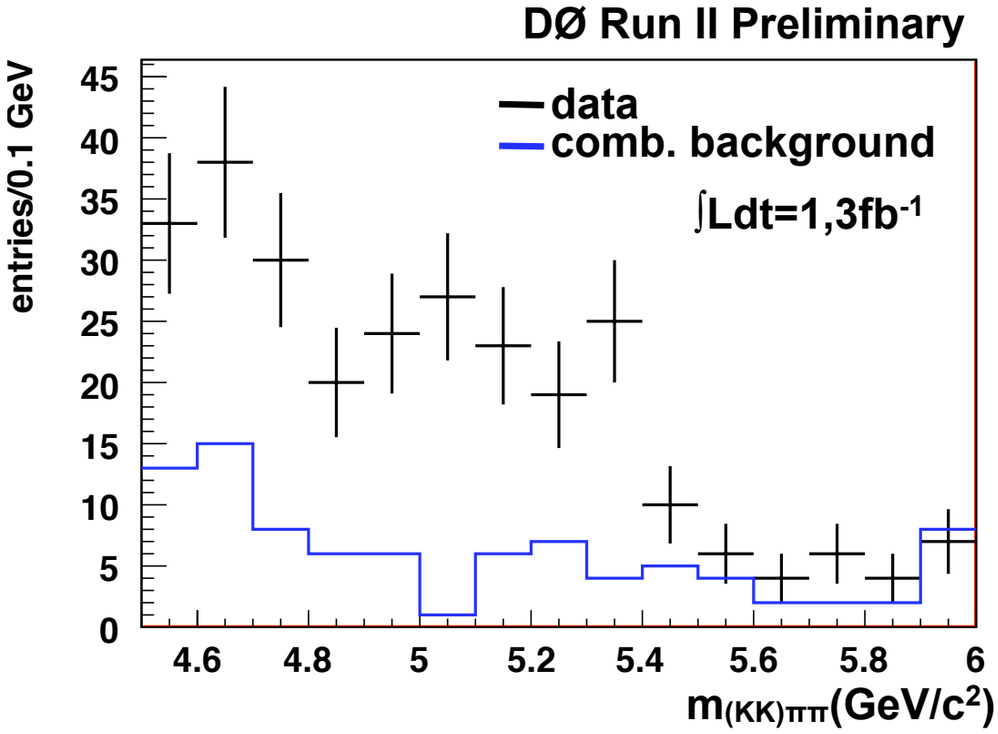
$B_s \to \mu^+ D_s^- (\phi\pi) X$

64500 semileptonic events





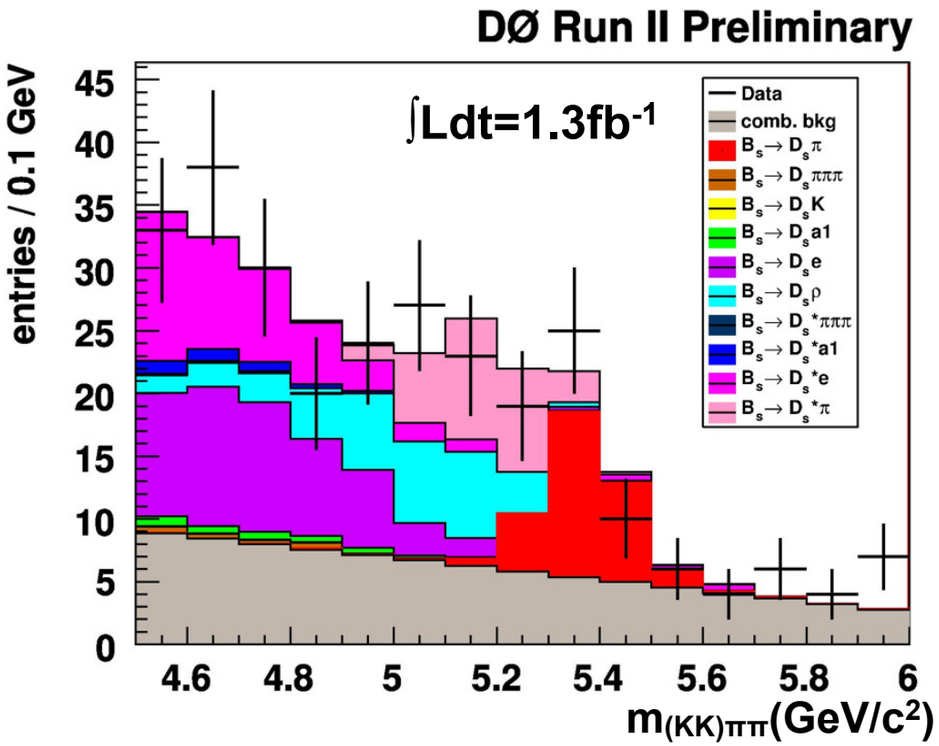
$B_s \to \pi^+ D_s^- (\phi\pi) X$



hadronic modes:
challenging task at DØ...

Hadronic Modes At DØ

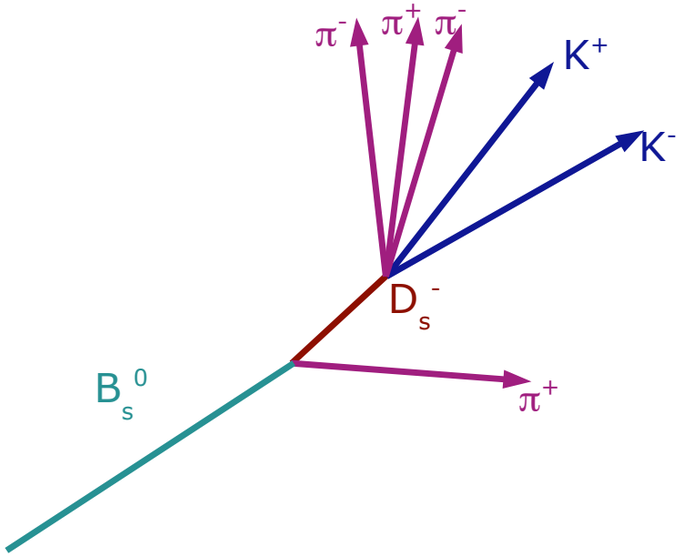
- can only be triggered by single muon triggers
- very low statistics
- challenging mass resolution
  - no signal peak → shoulder
  - take also partially reconstructed decays into account
- extensive MC studies to understand background



likelihood selection in hadronic and semileptonic mode

250 reconstructed and **tagged** hadronic events (trigger on opp. side μ)

→ CDF: (5600+3100)*5.5% ≈ 480 events



Decay Channels

CDF (data sample size: $\int L dt = 1 fb^{-1}$):

channel	candidates
$\bar{B}_s \to l^- D_s^+ X$	61500
$\bar{B}_s \to \pi^- D_s^+ (\phi\pi^+)$	2000
$\bar{B}_s \to \pi^- D_s^+ (K^*(892)^0 K^+)$	1400
$\bar{B}_s \to \pi^- D_s^+ (\pi^+\pi^-\pi^+)$	700
$\bar{B}_s \to \pi^-\pi^+\pi^- D_s^+ (\phi\pi^+)$	700
$\bar{B}_s \to \pi^-\pi^+\pi^- D_s^+ (K^*(892)^0 K^+)$	600
$\bar{B}_s \to \pi^-\pi^+\pi^- D_s^+ (\pi^+\pi^-\pi^+)$	200
partially reconstructed	3100

DØ (bigger dataset also includes resolution improvement through Layer0):

channel	candidates	improvements
$B_s \to \mu^+ D_s^- (\phi\pi^-) X$	44777±415	data: 1.3 fb^{-1} → 2.4 fb^{-1}
$B_s \to e^+ D_s^- (\phi\pi^-) X$	1663±102	data: 1.3 fb^{-1} → 2.4 fb^{-1}
$B_s \to \pi^+ D_s^- (\phi\pi^-) X$	249±17	new channel
$B_s \to \mu^+ D_s^- (K^{*0} K^-) X$	18098±903	data: 1.3 fb^{-1} → 2.4 fb^{-1}

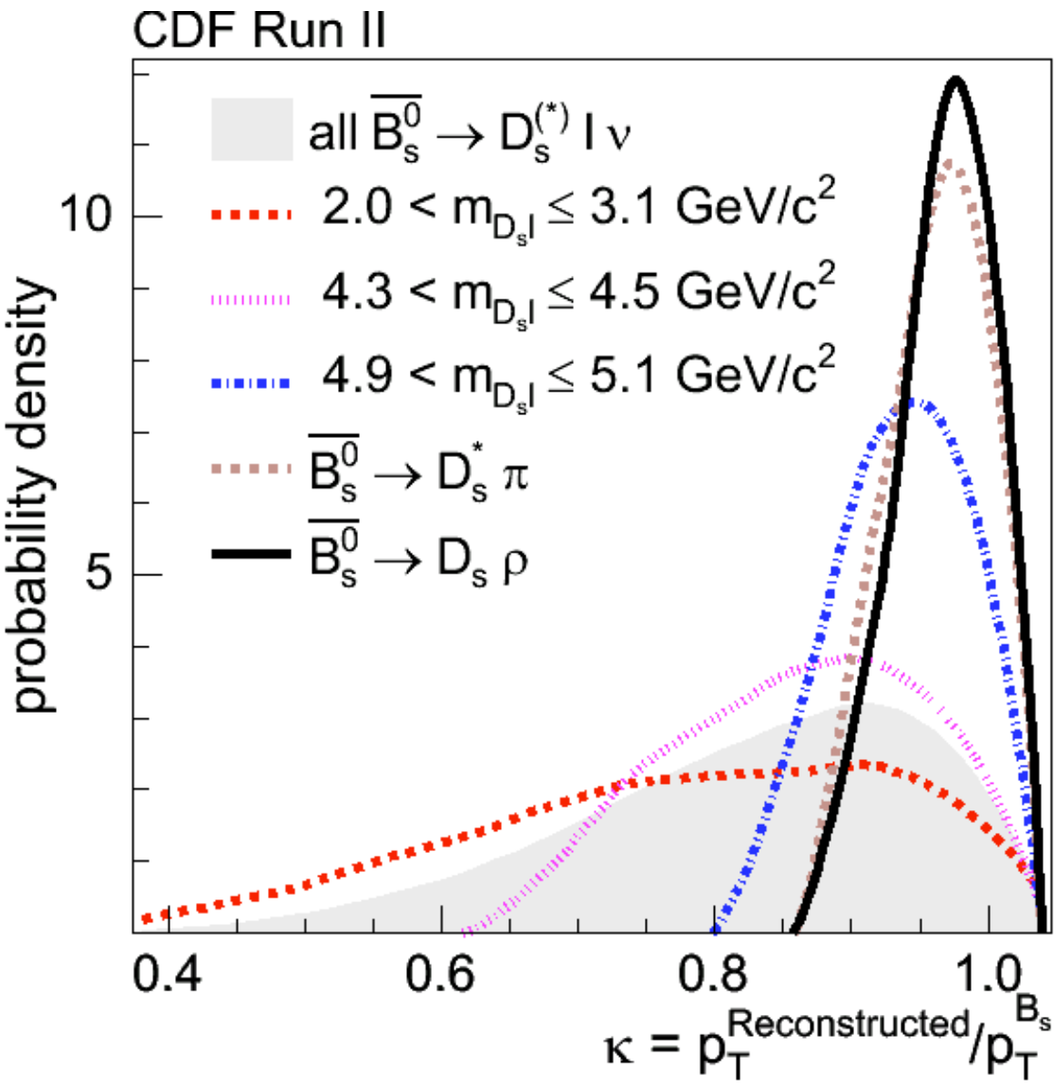
Decay Time Measurement

missing momentum, due to neutrino or un-reconstructed particle(s):

$$ct_{B_s^0} = L_{xy}^{\mu D_s} \cdot \frac{M_{B_s^0}}{p_T(\mu D_s)} \cdot \kappa$$

with: $\kappa \equiv \dfrac{p_T(\mu D_s)}{p_T(B_s^0)}$

κ determined through MC studies (DØ and CDF)



Initial State Tag

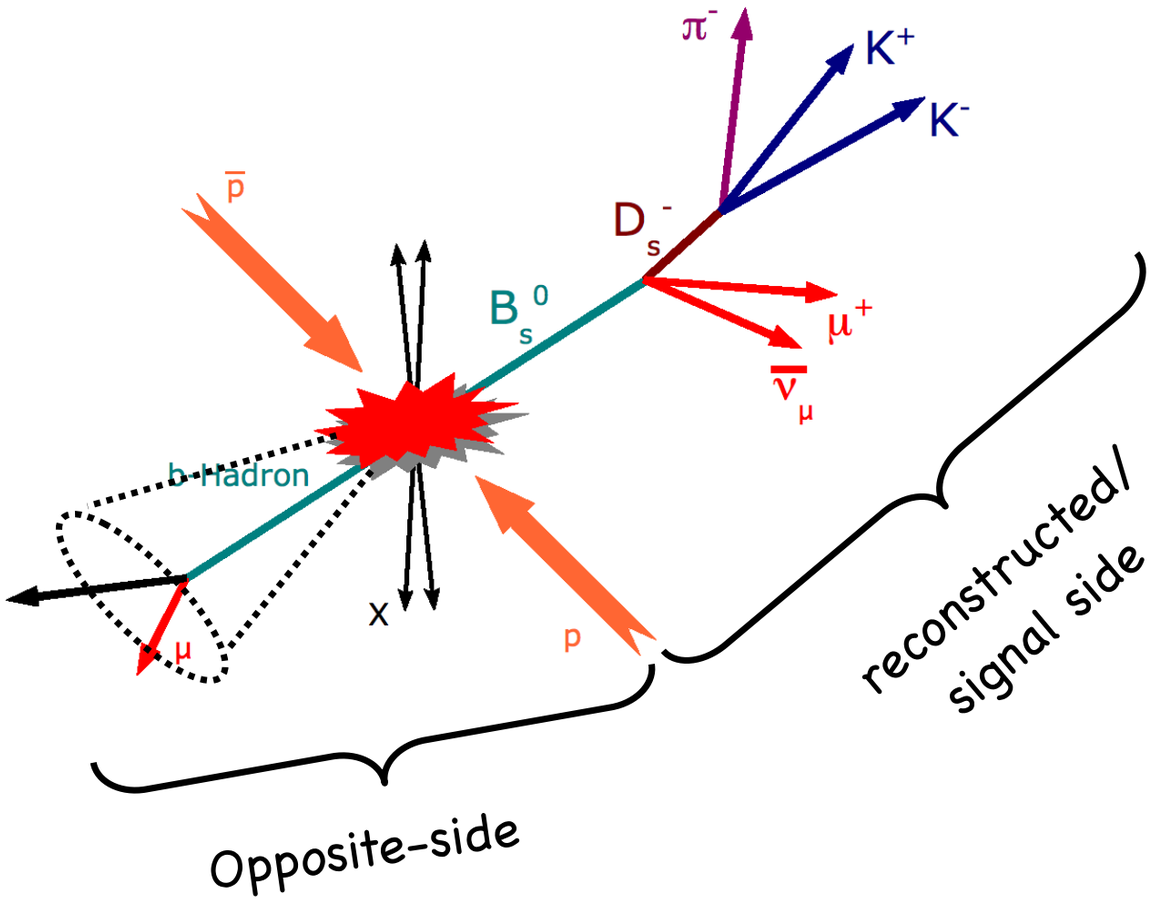
determine initial state: $\overline{B_s^0}$ or B_s^0

Same-side tagging (SST)

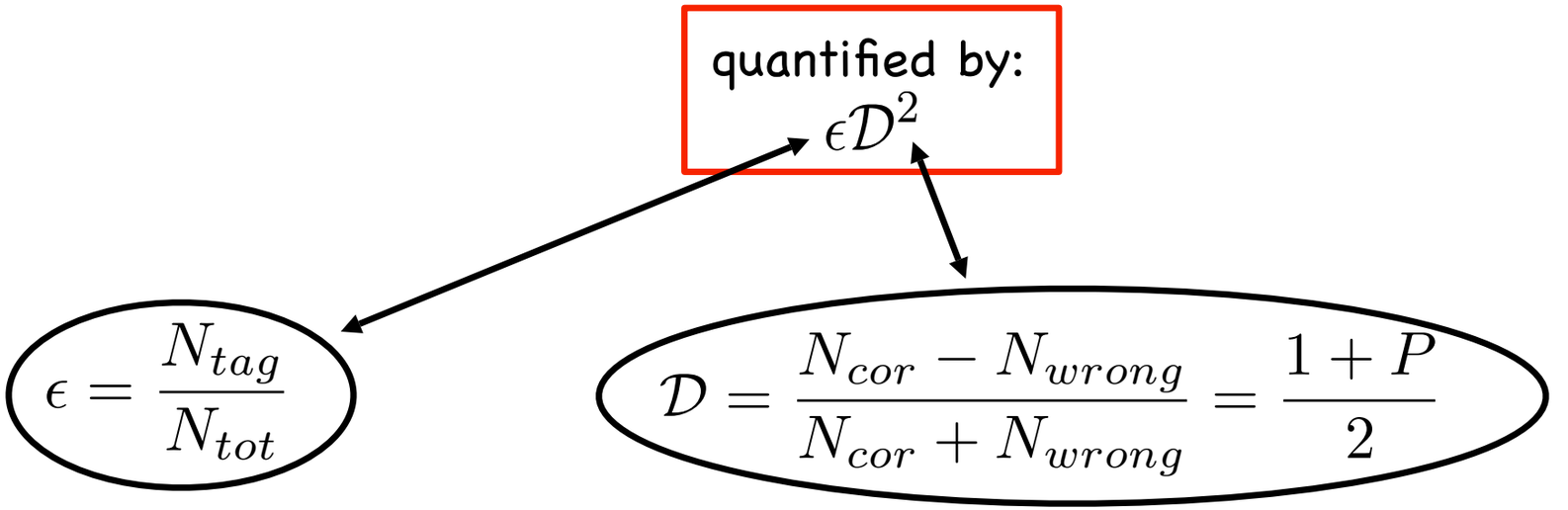
- charge correlation
- K in phase space close to B_s

Opposite-side tagging (OST)

- Lepton charge
- Jet charge
- Event charge
  - p_T-weighted tracks



Tagging Performance



OST power:

CDF: $\epsilon\mathcal{D}^2 = (1.8 \pm 0.1)\%$

DØ: $\epsilon\mathcal{D}^2 = (2.48 \pm 0.021(stat)^{+0.08}_{-0.06})\%$

determined with B_d data

SST power:

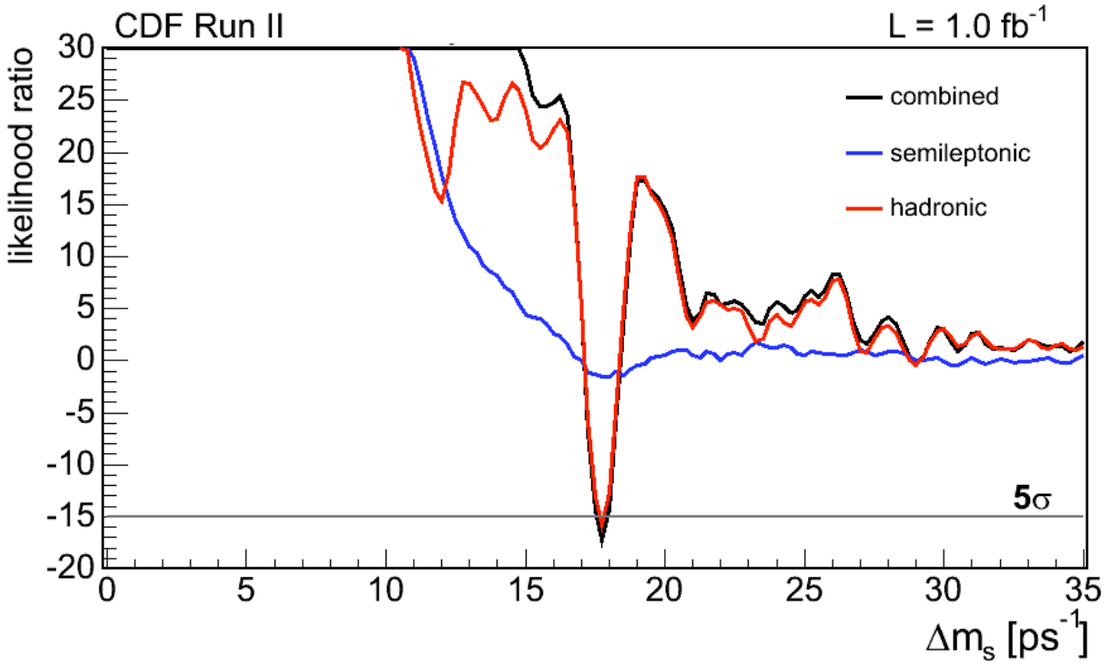
CDF: $\epsilon\mathcal{D}^2 = (3.7 \pm 0.9)\%$ hadronic modes

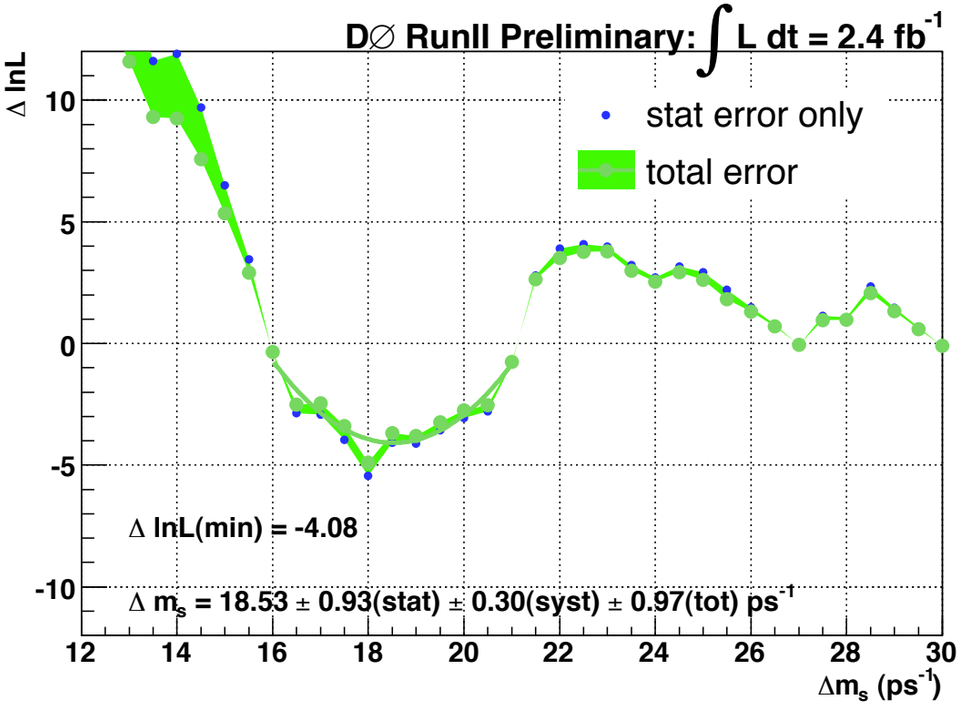
$\epsilon\mathcal{D}^2 = (4.8 \pm 1.2)\%$ semileptonic modes

DØ: $\epsilon\mathcal{D}^2 = (2.2 \pm 0.1)\%$ semileptonic modes

ANN: trained with MC, tested with B_d-samples

Δm_s Result





CDF:

$$\Delta m_s = (17.77 \pm 0.10_{stat} \pm 0.07_{sys})\mathrm{ps}^{-1}$$

- blind analysis
- benefits from displaced vertex track trigger
  - ➙ large fully reconstructed sample

DØ:

$$\Delta m_s = (18.53 \pm 0.93_{stat} \pm 0.30_{sys})\mathrm{ps}^{-1}$$

hadronic modes: no uncertainties due to neutrino

➙ very important for precise measurement of Δm_s

Conclusion

- CDF and DØ: first experiments to measure Δm_s
- DØ: improvements in semileptonic channel + access to hadronic modes: 3σ result

CDF: $\Delta m_s = (17.77 \pm 0.10_{stat} \pm 0.07_{sys})\text{ps}^{-1}$

DØ: $\Delta m_s = (18.53 \pm 0.93_{stat} \pm 0.30_{sys})\text{ps}^{-1}$

- information on $\frac{|V_{td}|}{|V_{ts}|}$
  - now dominated by theoretical uncertainties

CDF: $\frac{|V_{td}|}{|V_{ts}|} = 0.2060 \pm 0.0007(exp)^{+0.0081}_{-0.0060}(theor)$

DØ: $\frac{|V_{td}|}{|V_{ts}|} = 0.2018 \pm 0.005(exp)^{+0.0079}_{-0.0059}(theor)$

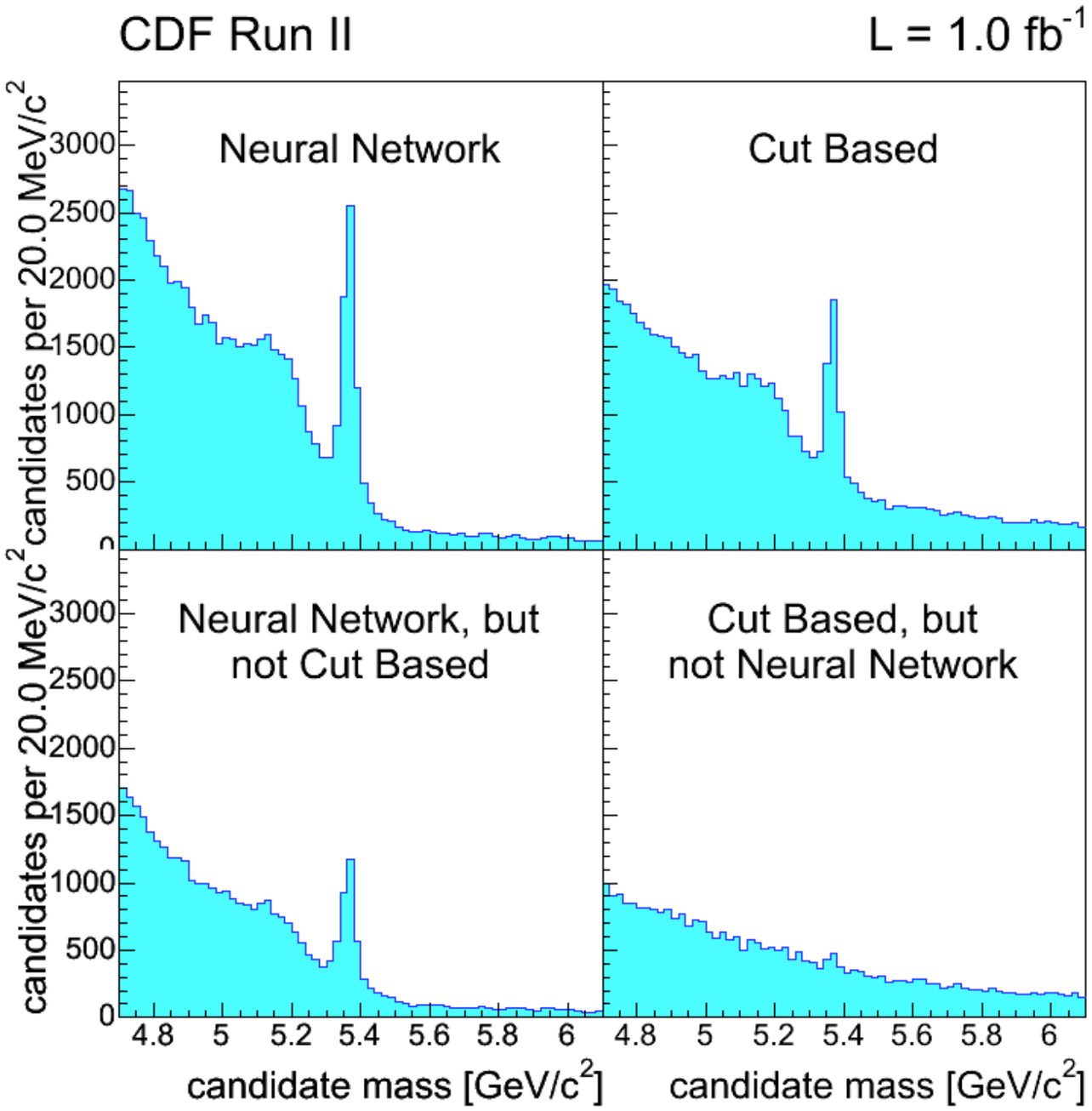
- "personal" world averages (calculated by myself):

$$\Delta m_s = (17.78 \pm 0.12)\text{ps}^{-1}$$

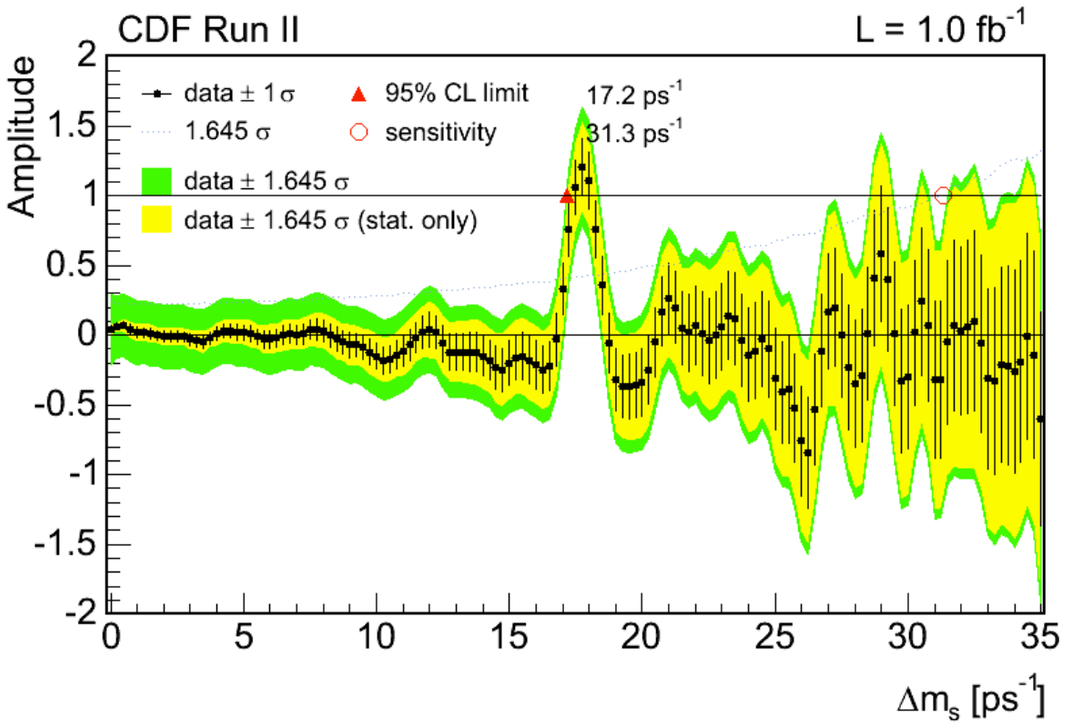
$$\frac{|V_{td}|}{|V_{ts}|} = 0.2059 \pm 0.0007(exp)^{+0.0081}_{-0.0060}(theor)$$

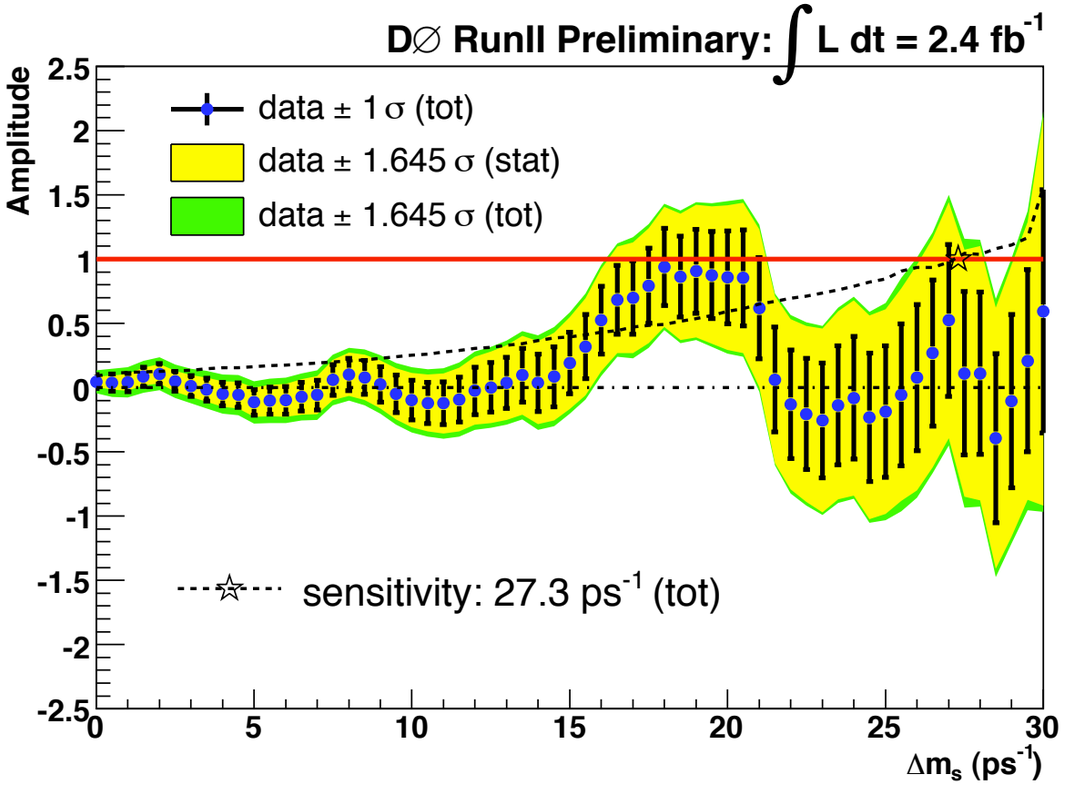
Backup

Neural Network (CDF)

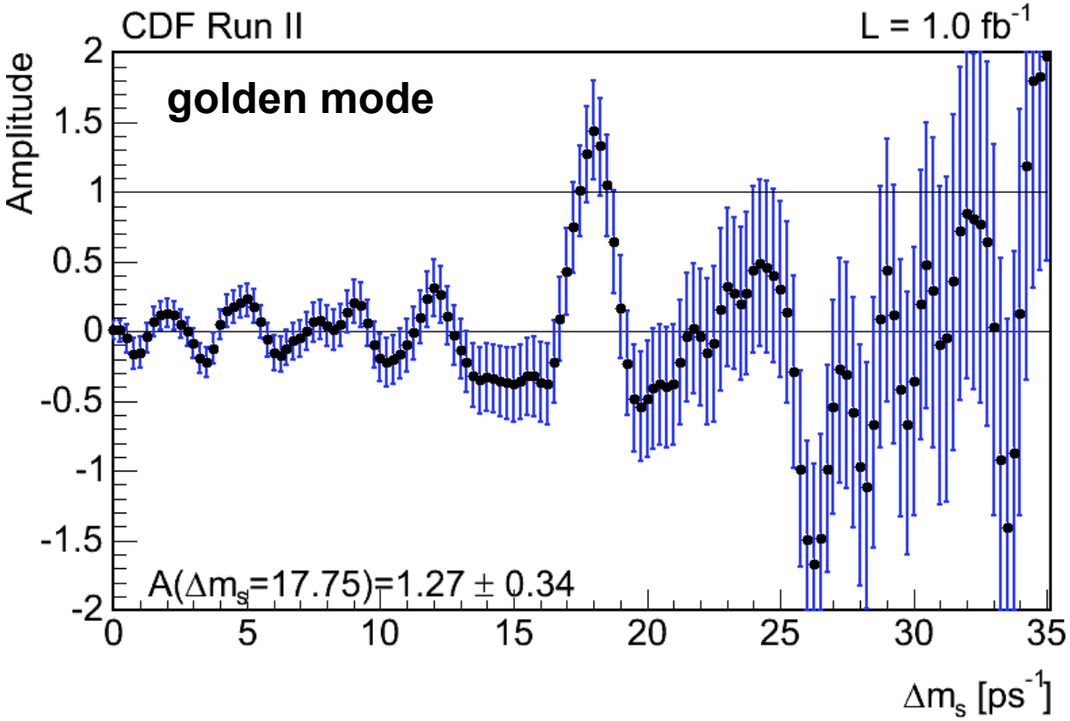


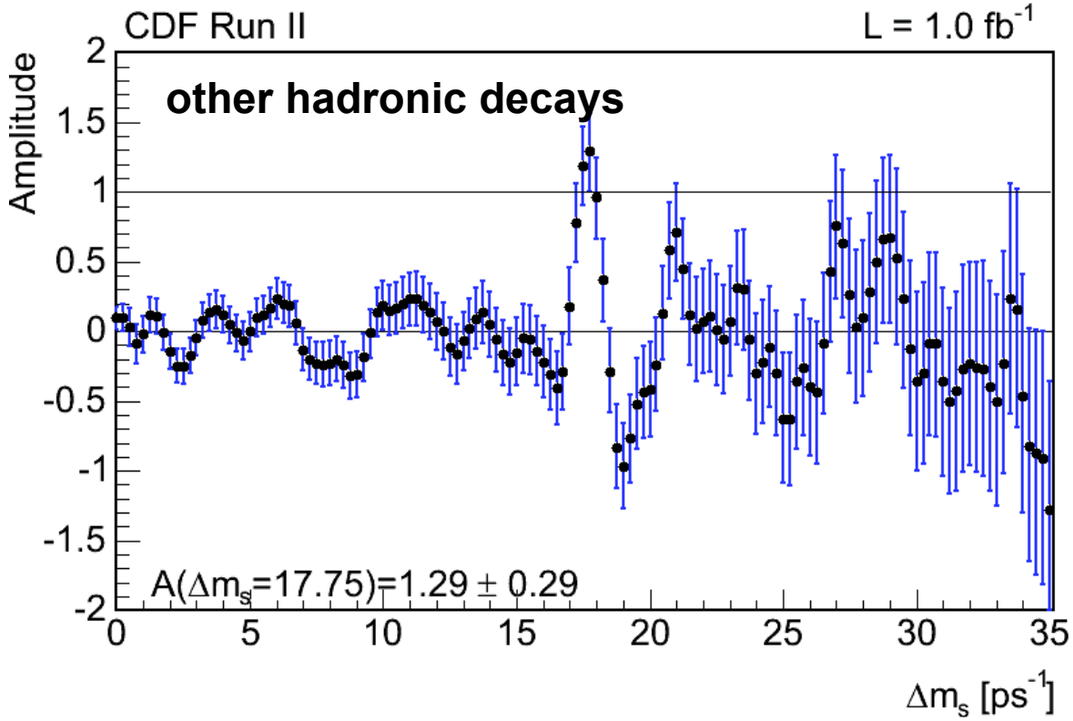
Amplitude Scans

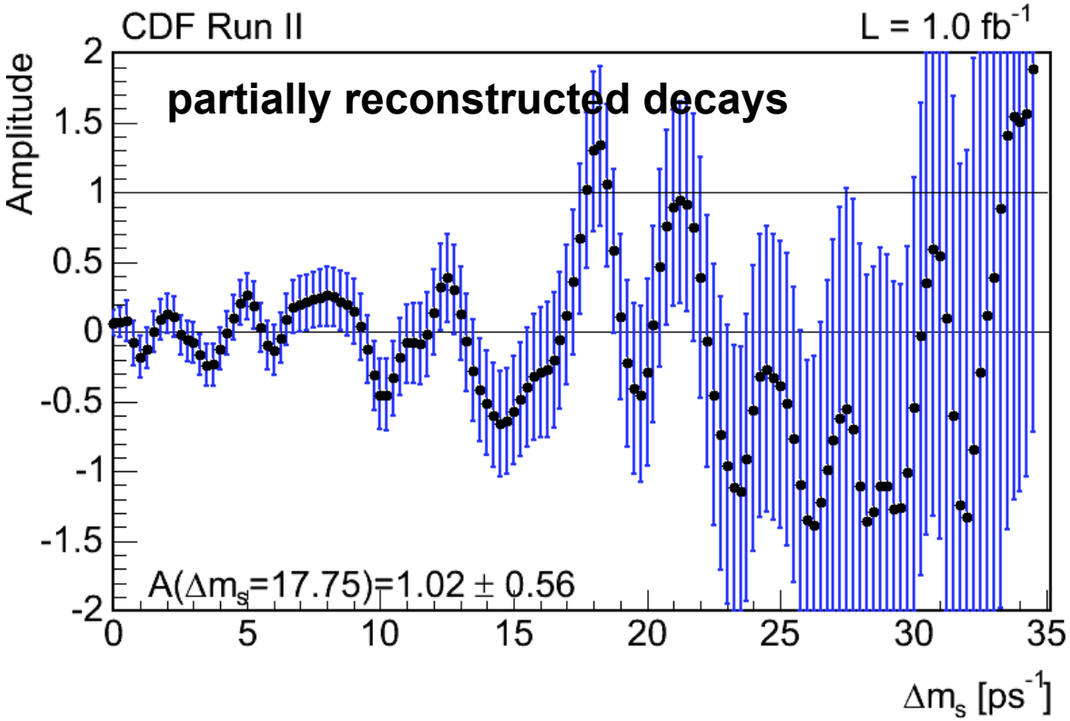


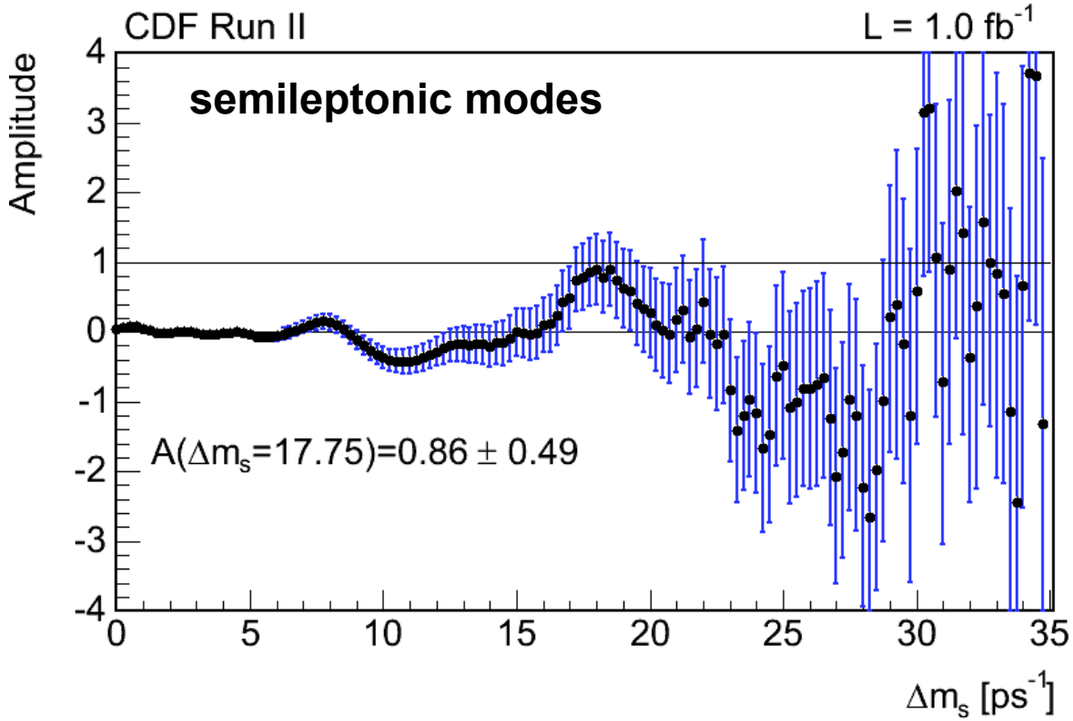


Amplitude Scans (CDF)

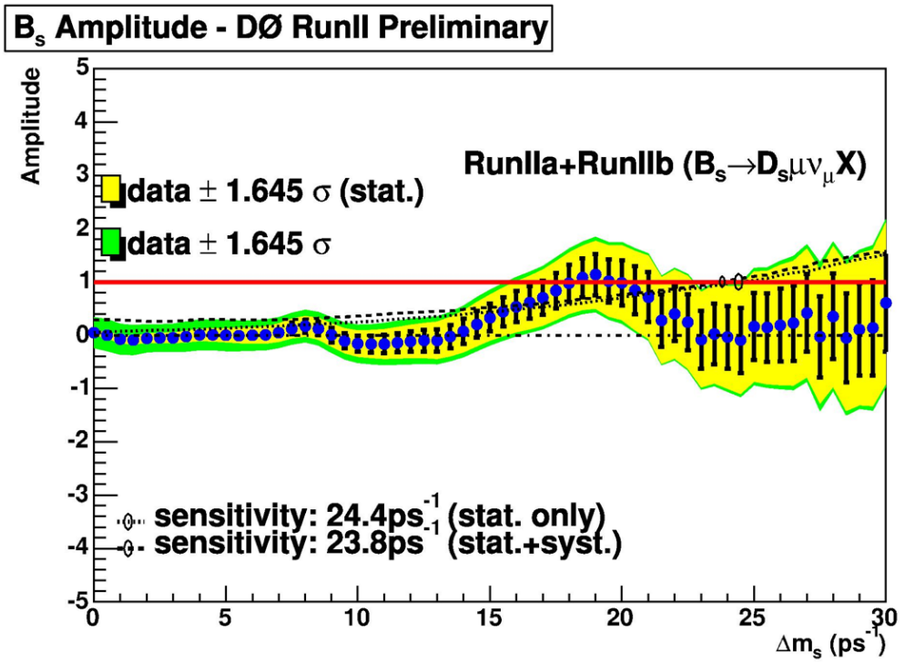


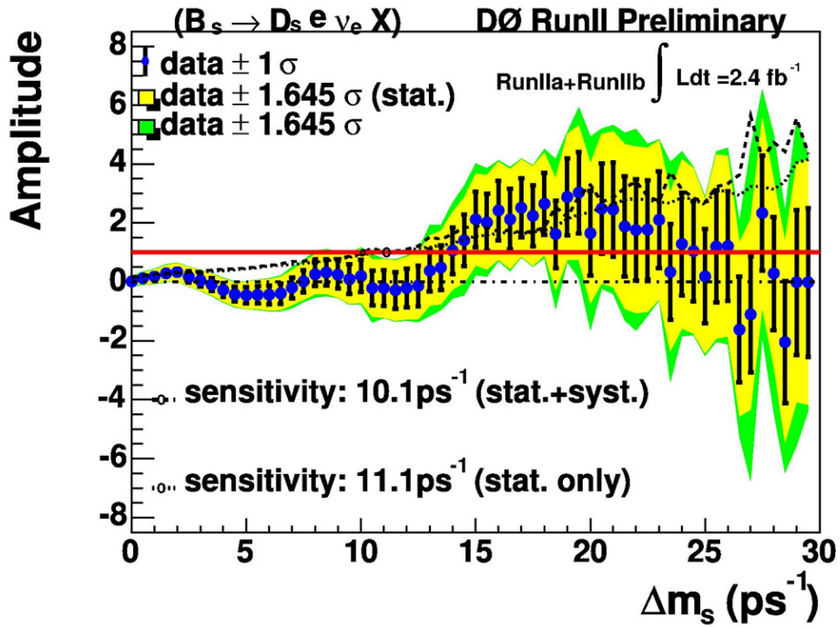


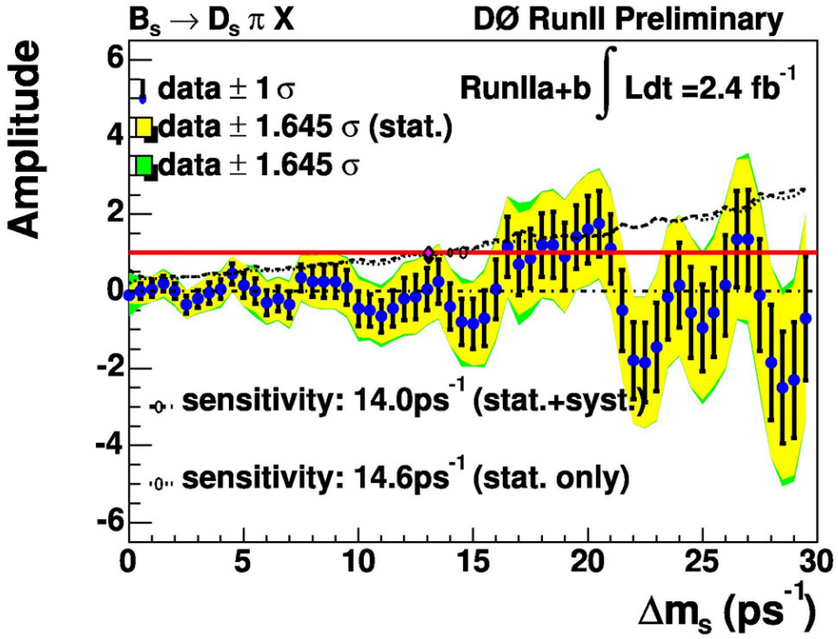




Amplitude Scans (DØ)







Signal Samples (DØ)