DØ Results on Neutral B Meson Flavor Oscillations

Gernot A. Weber
On Behalf of the DØ Collaboration, CKM 2006

- Motivation
- Tevatron & DØ detector
- B_s oscillations
  - Published results
  - Preliminary results
- Conclusion and outlook

bmb+f Großgeräte der physikalischen Grundlagenforschung

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Motivation and Method

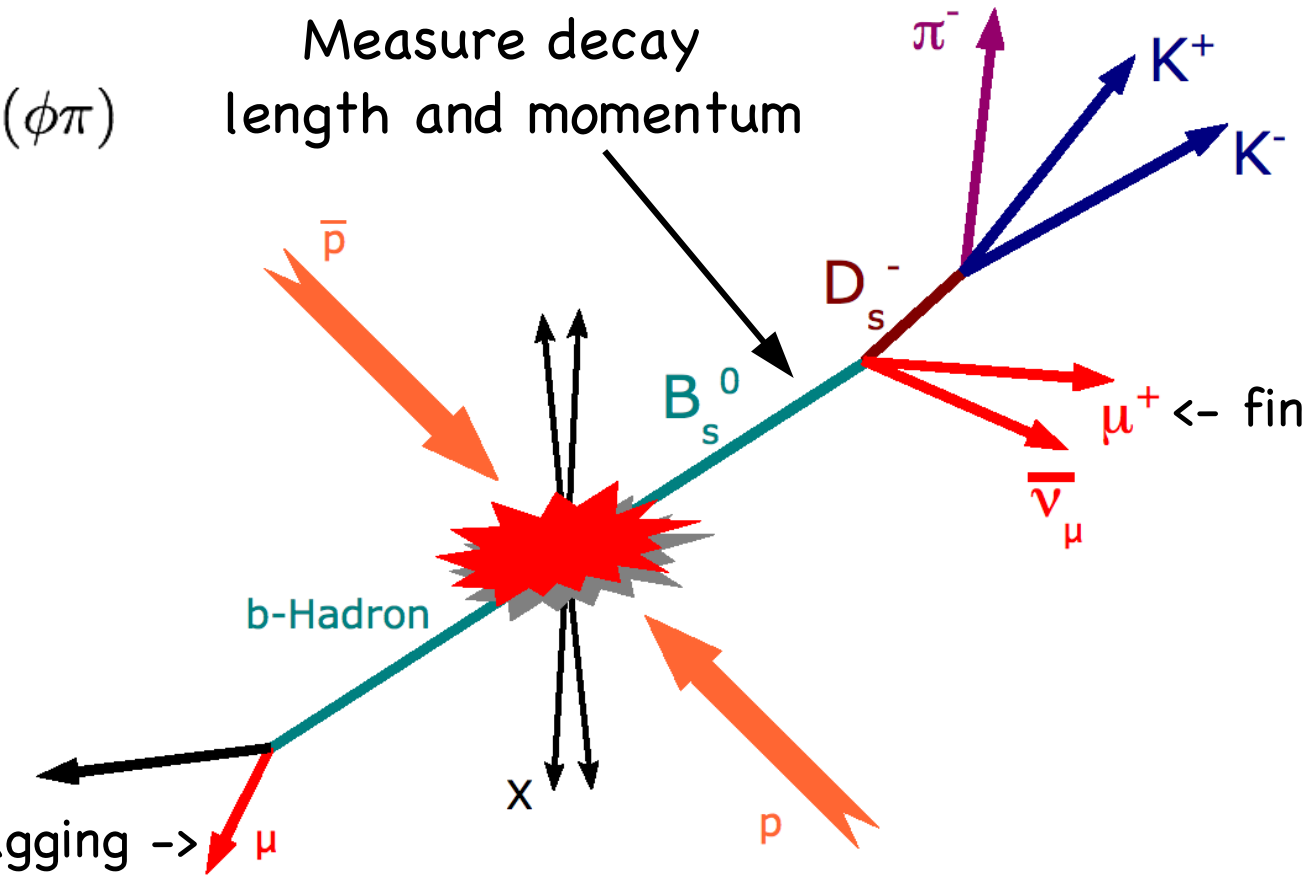
Want to measure CKM matrix element $|V_{td}|$

Measure B_s oscillations to reduce hadronic uncertainties

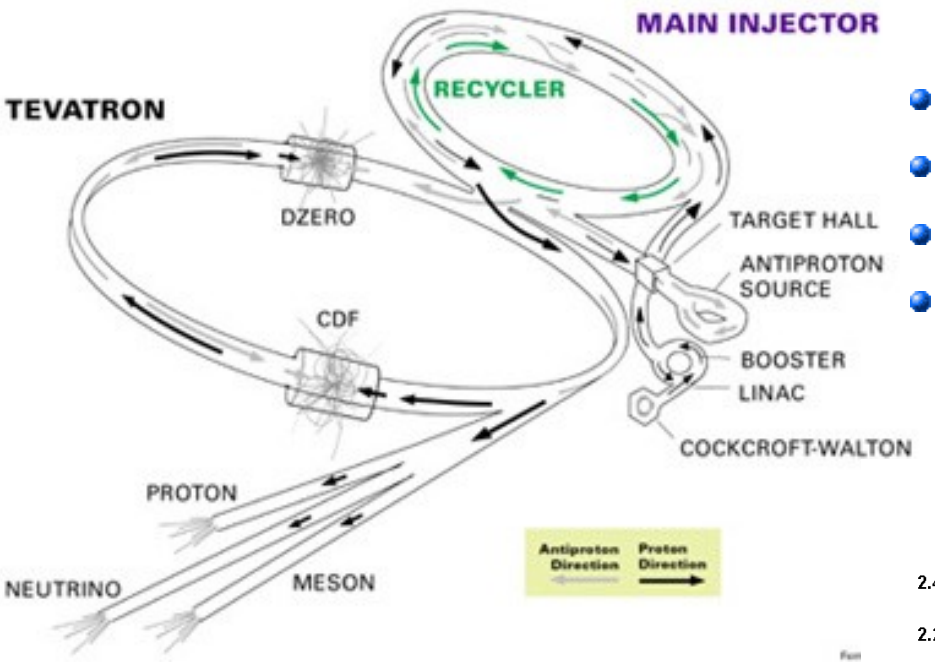
Example:

$B_s \to \mu\nu_\mu D_s(\phi\pi)$

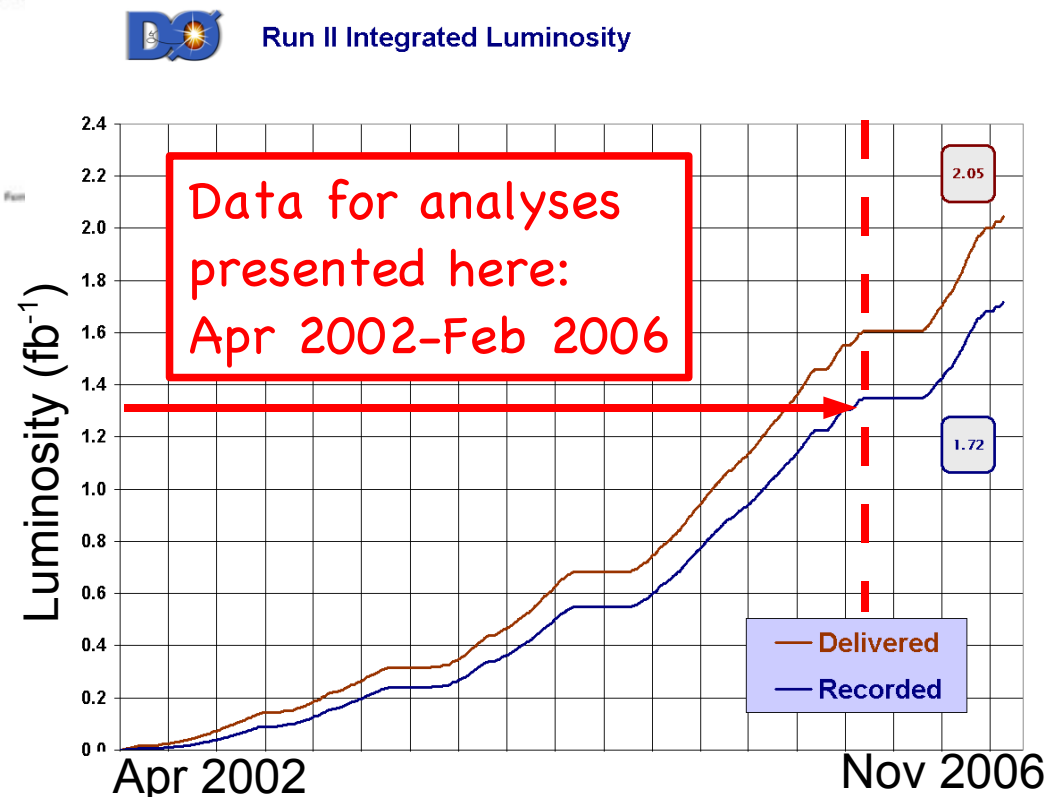
Measure decay length and momentum



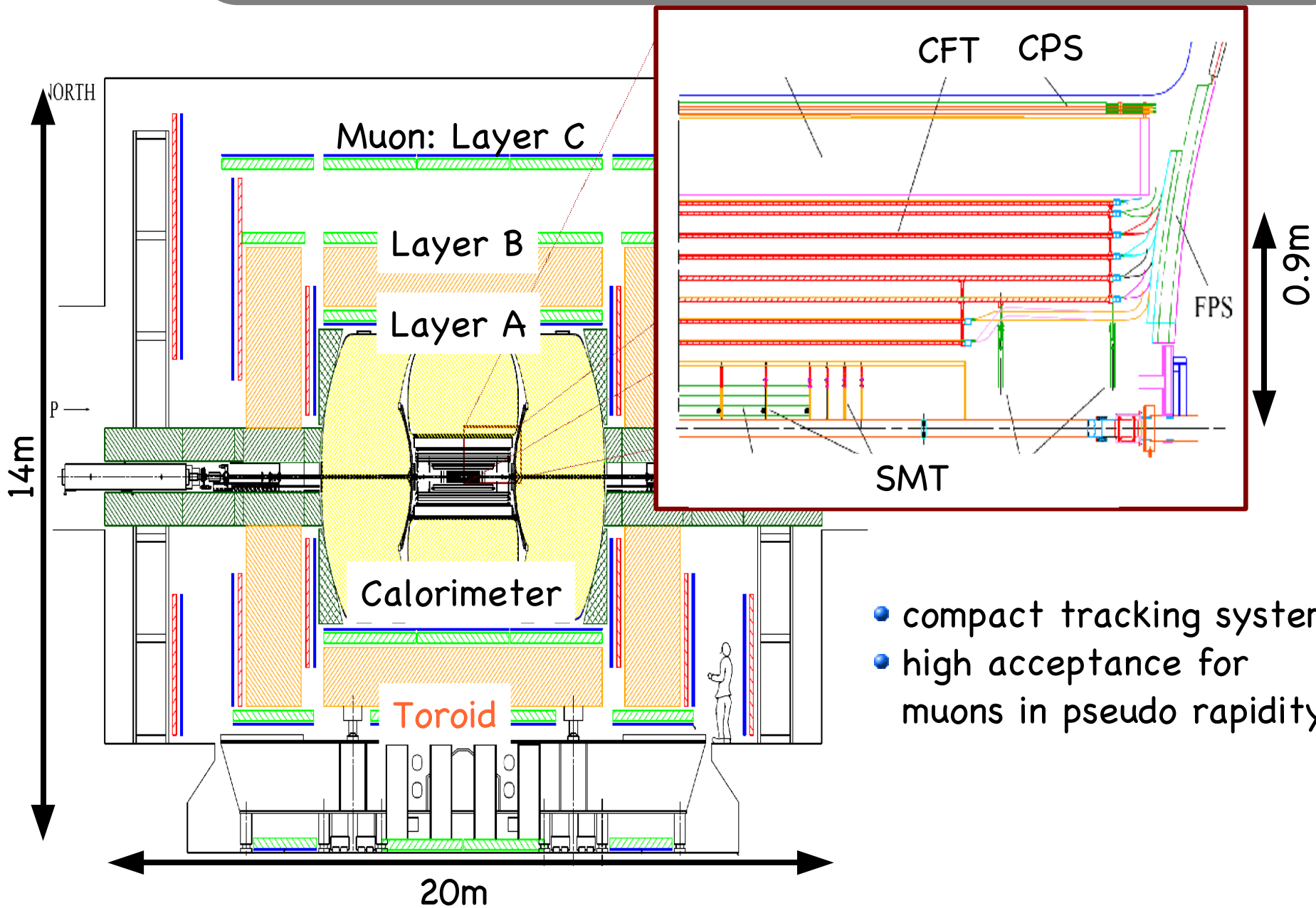
Tevatron



- $p\bar{p}$ collisions @ $\sqrt{s}$ = 1.96 TeV
- Bunch spacing: 396 ns
- Inst. luminosity record: $232 \cdot 10^{30}$ $cm^{-2}s^{-1}$
- Currently the only place to study B_s-mixing



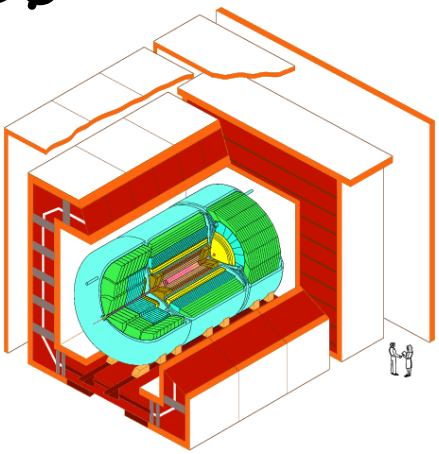
DØ-Detector



- compact tracking system
- high acceptance for muons in pseudo rapidity

Comparing the Detectors

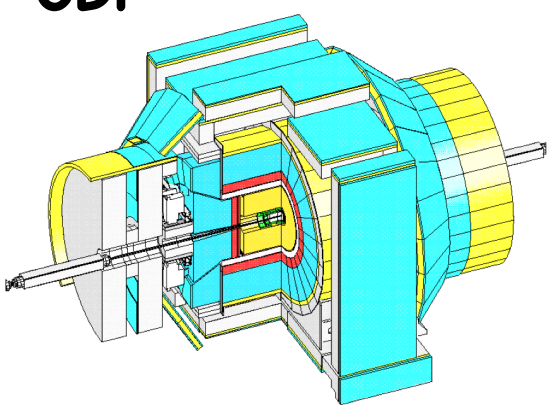
DØ



- Higher muon η coverage: $|\eta| < 2$
- B_s mostly triggered on muons

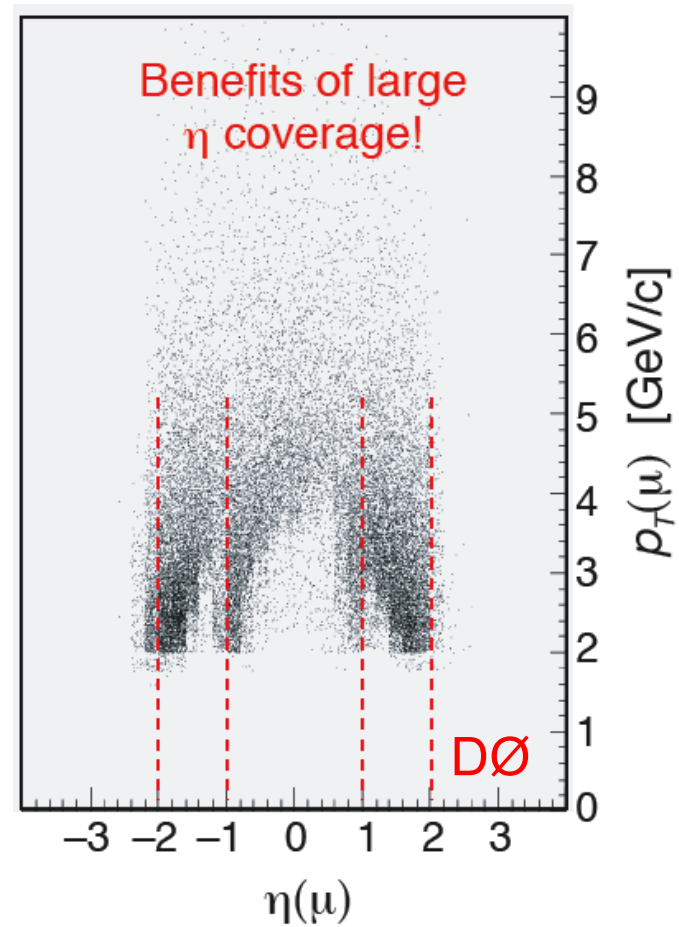
⇒ **mostly semileptonic decays**

CDF

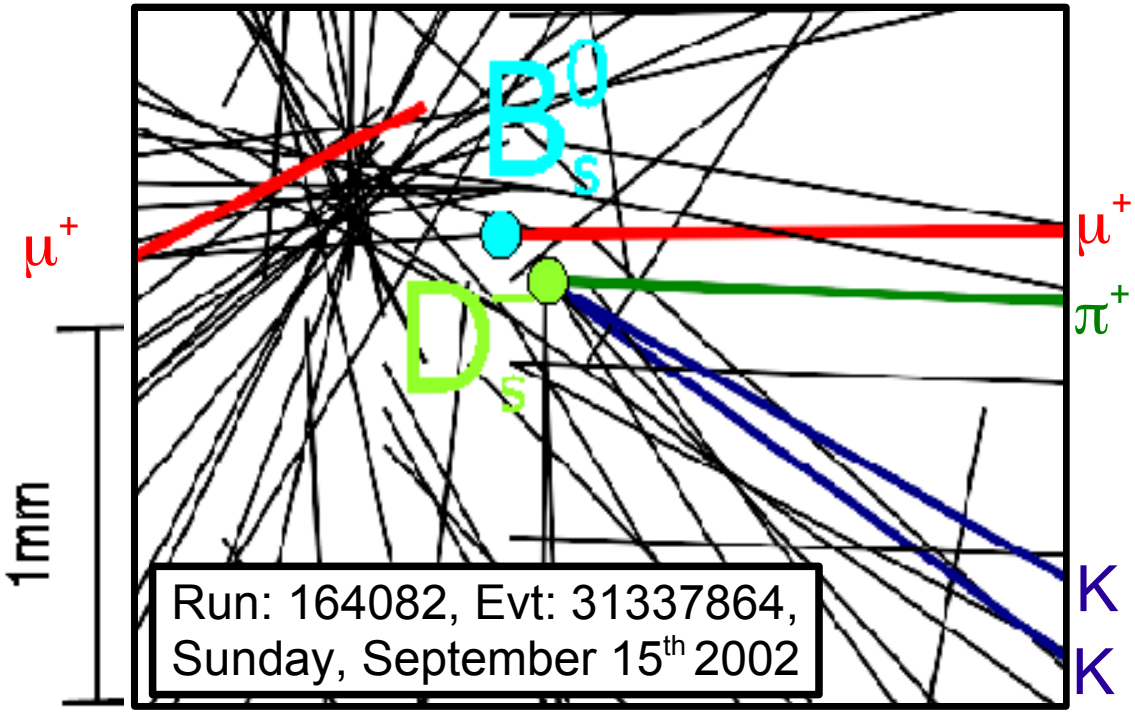


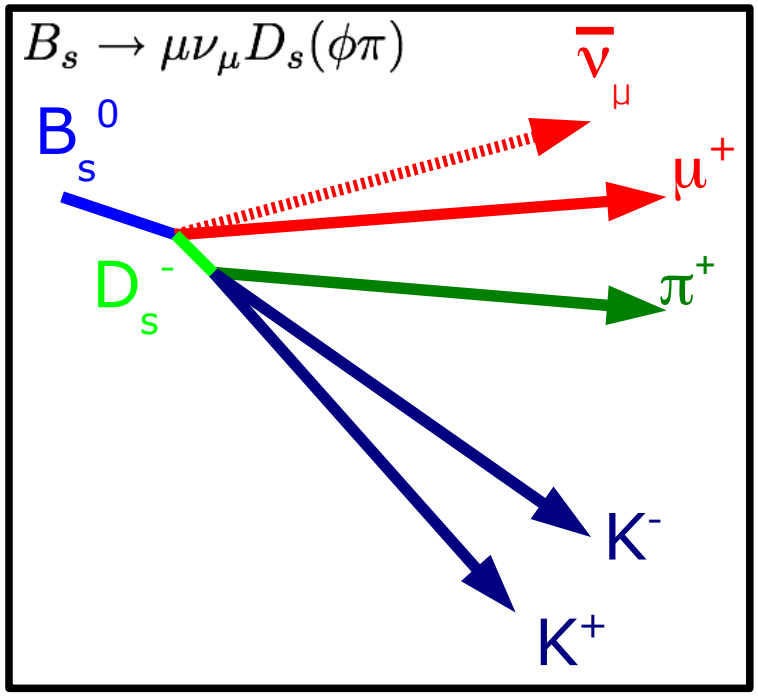
- Smaller muon η coverage: $|\eta| < 1$
- Efficient track trigger

⇒ **hadronic modes easy accessable**



B Production at Hadron Colliders





- Production of B mesons "messy" ⇒ many tracks per event
- Immersed in a large background ⇒ not easy to get clean signal
- Really hard to trigger events

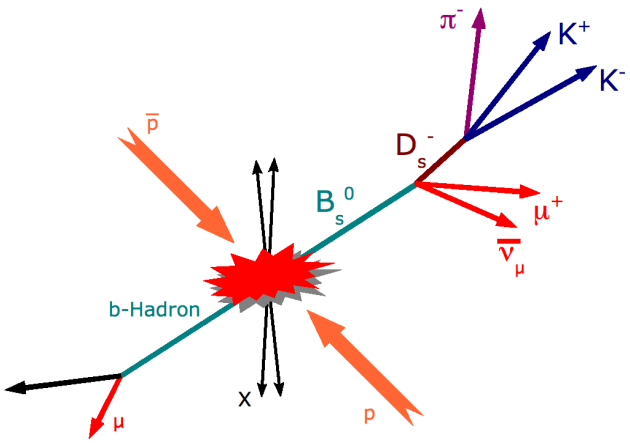
  ⇒ important: high muon acceptance as we have at DØ

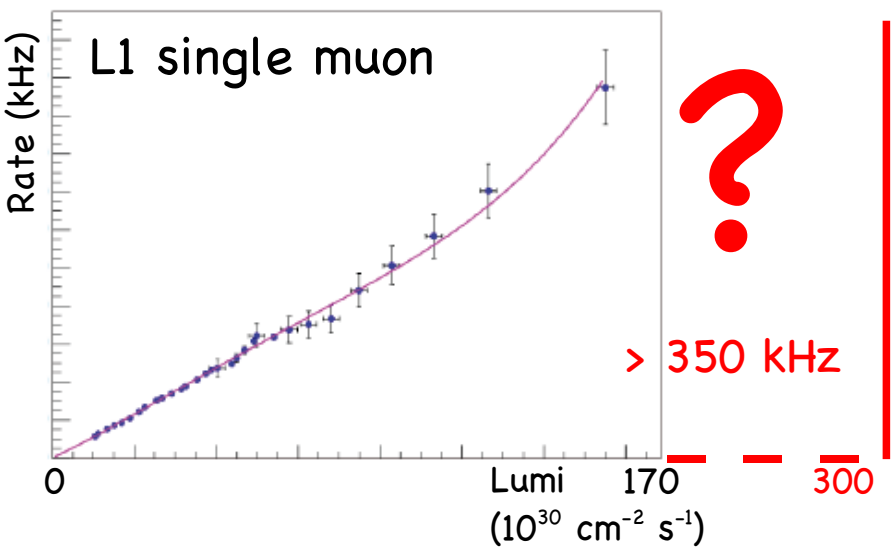
Trigger Strategies

DØ uses 3 level trigger system

signatures to trigger B_s candidates:

- presence of μ (all trigger levels)
- Cut on ϕ mass (only Level 3)
- Cut on significance of impact parameter (only Level 3)





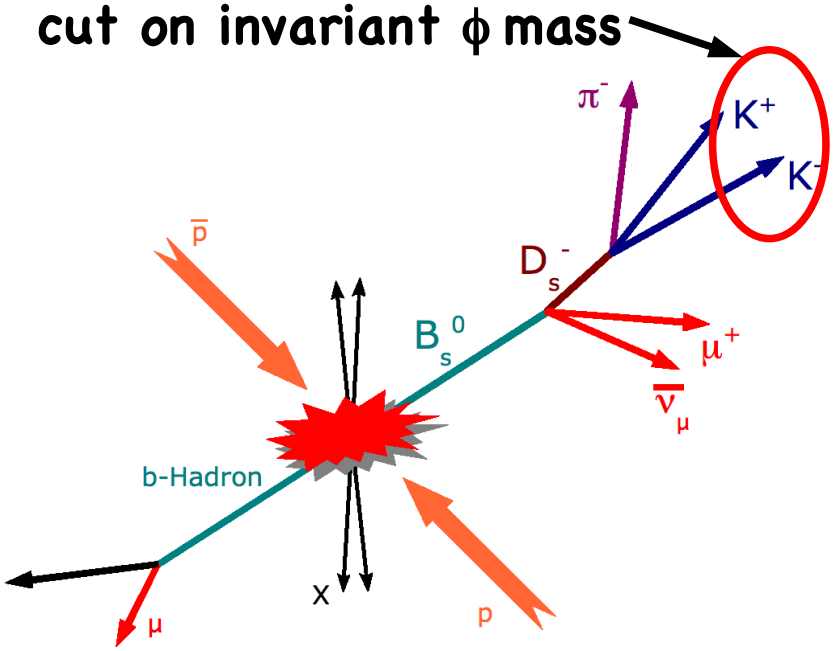
- Tevatron pushes to higher luminosities
  ⇒ How will the rate evolve?
- Trigger-rate limitation on each trigger-level?
- Combinatorical background increases faster than linear

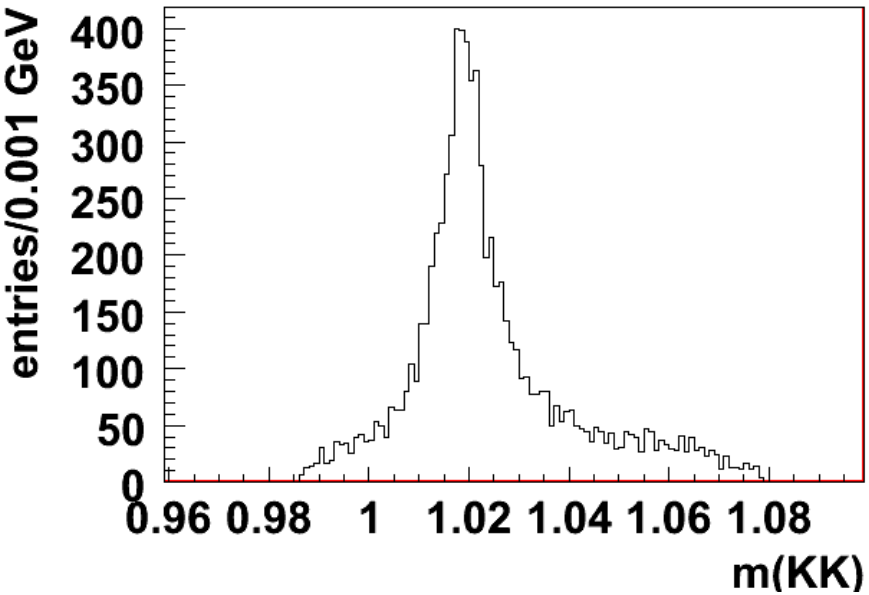
B-Physics Triggers

What to do to retain trigger rate, while increasing efficiency?

- PROBLEM: Increasing threshold on muon p_T will significantly cut signal
- BUT: Level 3 is able to reconstruct events and trigger on physics signatures
  ⇒ Create/Optimize triggers cutting on decay typical properties, i.e. invariant masses, impact parameters,...

Example:
cut on invariant ϕ mass





Reconstructed invariant KK-mass from events triggered by ϕ-mass trigger

Analysis steps

For $B_{(d,s)}$ mixing analysis we need to:

- Tag final state flavor
  - Reconstruct and select events
- Measure proper decay length of B-meson
- Tag initial state flavor

Decay Time Measurement

- Decay time given by:

$$t_{B_s^0} = L_{xy}^B \cdot \frac{M_{B_s^0}}{p_T(B_s^0)}$$

- ν has missing momentum -> take visible proper decay length

$$x^M \equiv L_{xy}^{\mu D_s} \cdot \frac{M_{B_s^0}}{p_T(\mu D_s)} \cdot c$$

-> decay time:

$$t_{B_s^0} = \frac{x^M}{c} \cdot K \qquad K \equiv \frac{p_T(\mu D_s)}{p_T(B_s^0)}$$

- Uncertainty for time measurement

$$\sigma_t = \sigma\left(\frac{L_{xy}^{\mu D_s}}{c}\right) \oplus \left(t \cdot \frac{\sigma(K)}{K}\right)$$

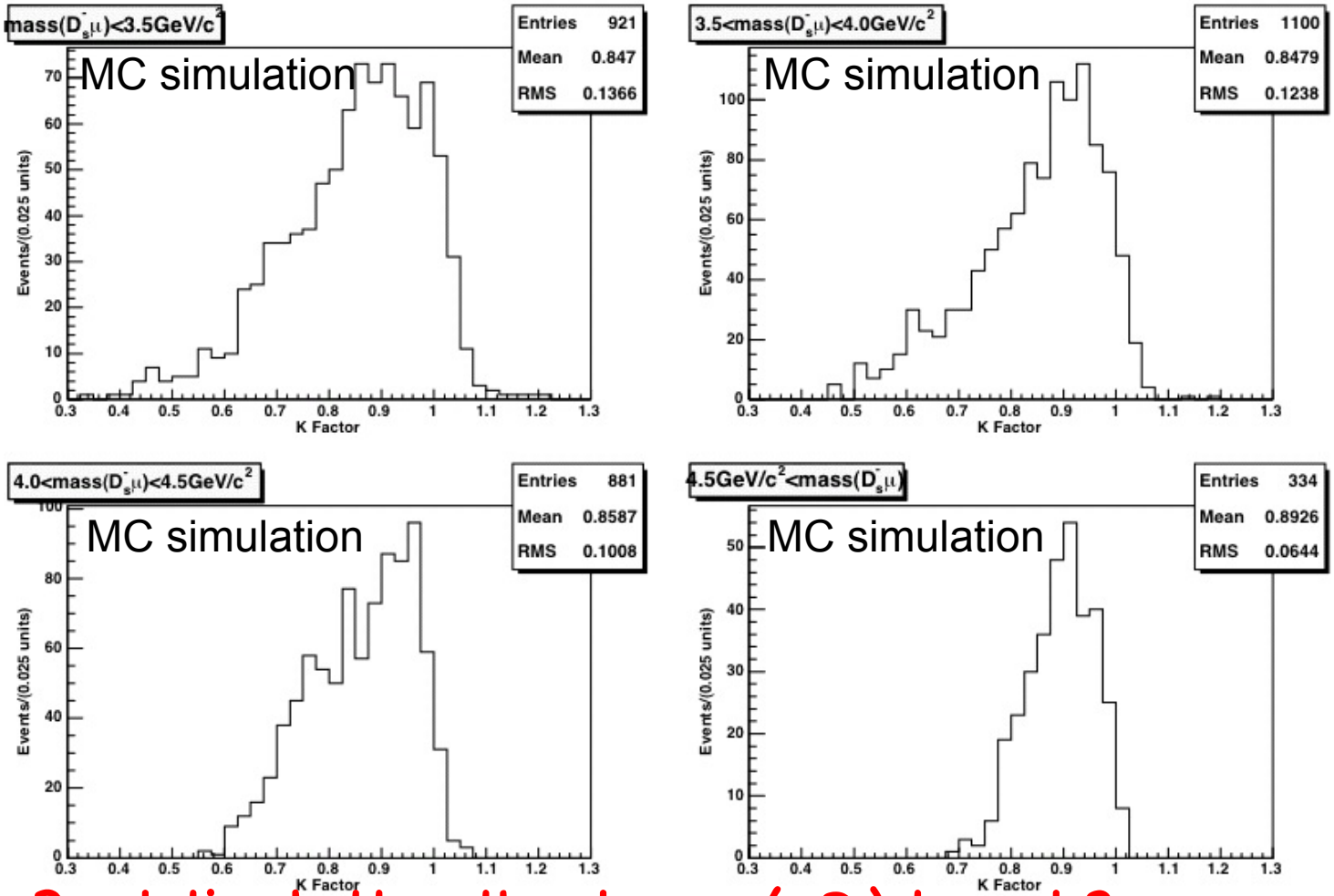
-> K << 1: high uncertainty for σ_t

-> σ(K) high: high uncertainty for σ_t

K-Factors

Take into account: missing momentum of ν

-> four different (μ D_s) mass ranges



Resolution better, the closer m(μ D_s) to real B_s mass

<-> the less correction of missing momentum from ν

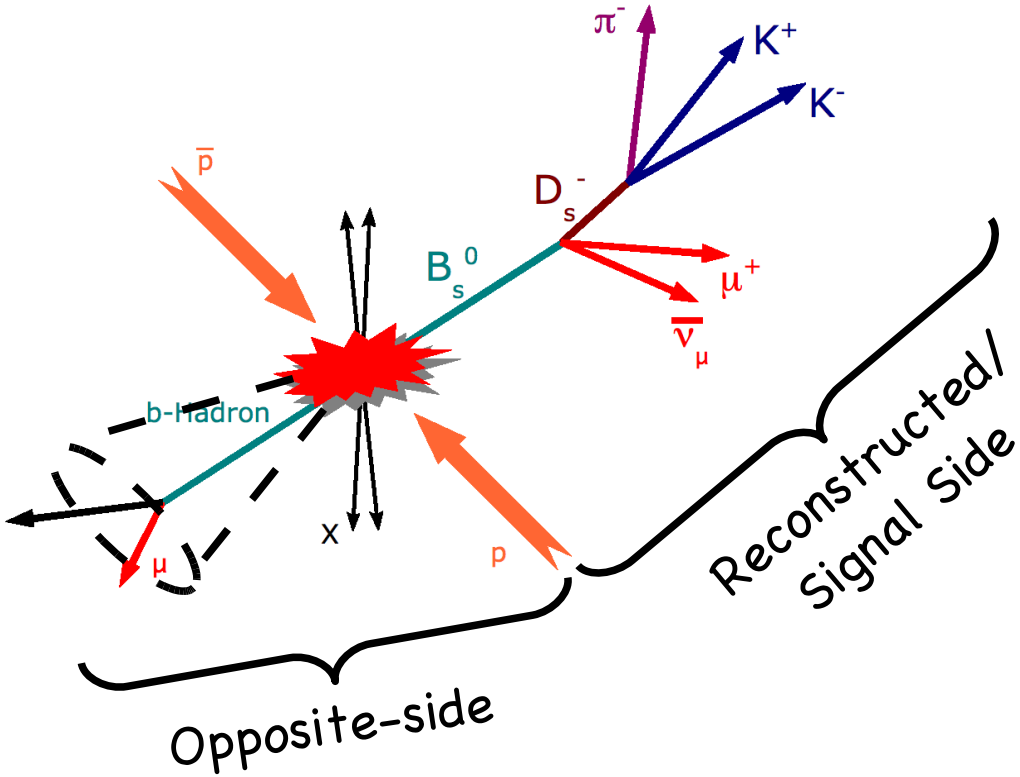
Initial Flavor Tagging

Analyses presented here:

Opposite-side tagging (OST)

- use charge of decay lepton
- jet charge
- event charge

for initial flavor tagging



Tagging algorithm independent of decay on signal side, i.e.

$$OST(B_d \to \mu + X) = OST(B_s \to \mu + X)$$

Determine Tagging Power

Use well measured B_d oscillation to determine tagging power

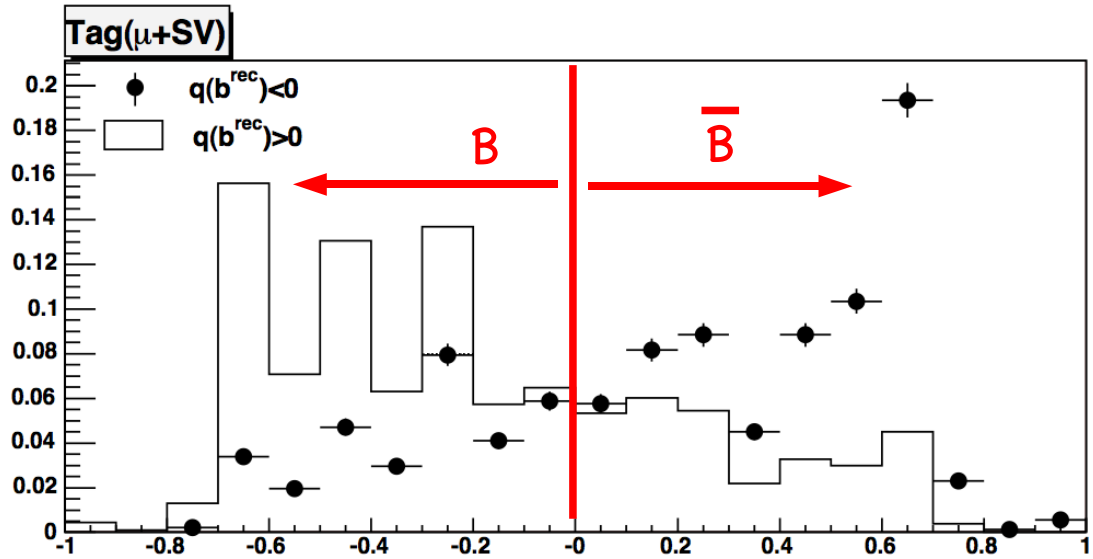
Quantification of tagging-power:

$$\epsilon \cdot \mathcal{D}^2$$

$$\epsilon = \frac{N_{tag}}{N_{tot}}$$

$$\mathcal{D} = \frac{N_{cor} - N_{wrong}}{N_{cor} + N_{wrong}} = \frac{N_{cor} - N_{wrong}}{N_{tag}}$$

Likelihood: combination of all tagging variables
⇒ tagging variable d

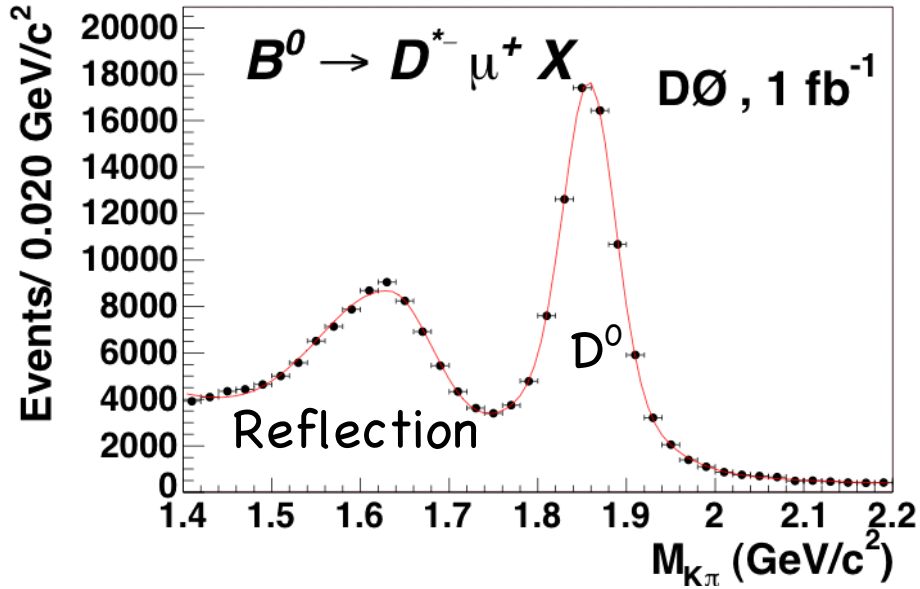


tagging variable d

Consistency Check: B_d Mixing

- Dilutions found to be the same for analyzed B_d decays

  -> justifies application to B_s



- Mixing parameter found to be in good agreement with world average:

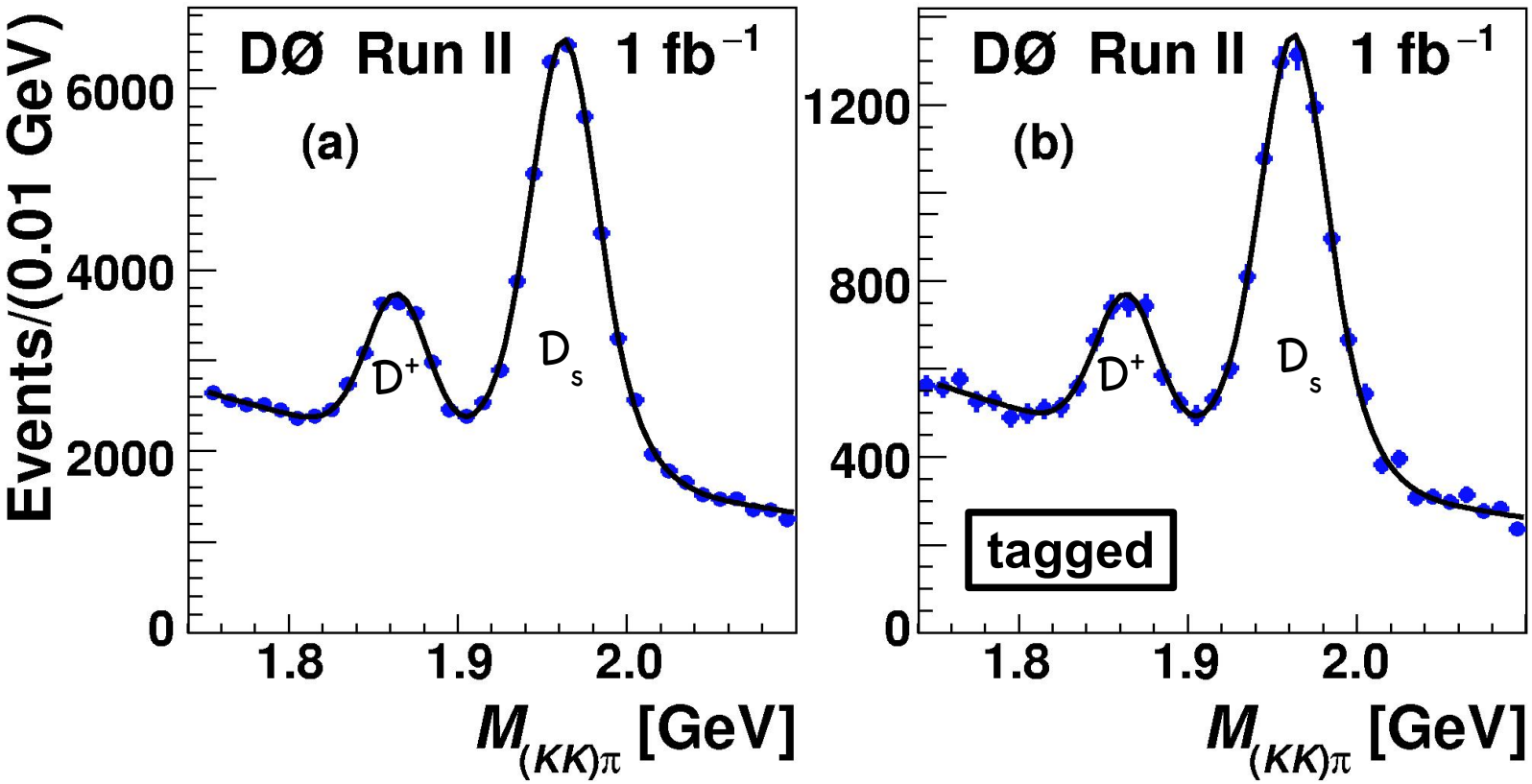
$$\Delta m_d = 0.506 \pm 0.020 \ \ (\text{stat}) \pm 0.016 \ \ (\text{syst}) \ \ \text{ps}^{-1}$$

- Combined tagging power found to be (hep-ex/0609034, FERMILAB-PUB-06/341-E; Accepted by Phys. Rev. D.):

$$\epsilon\mathcal{D}^2 = [2.48 \pm 0.021 \ \ (\text{stat})^{+0.08}_{-0.06} \ \ (\text{syst})]\%$$

Signal Selection

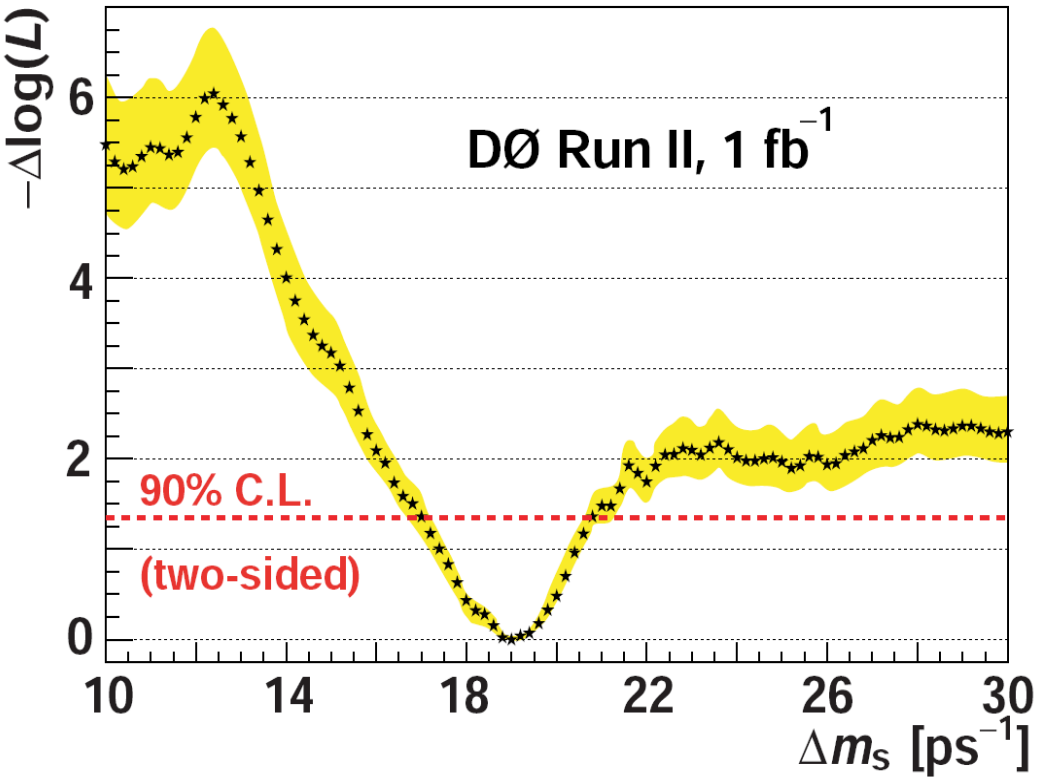
$$B_s \to \mu\nu_\mu D_s(\phi\pi)$$



- Big semileptonic B_s sample ≈ 25k events
- After tagging: ≈ 5k events
- ε ≈ 20%
- PRL 97, 021802 (2006)

Published Results on Δm_s

Likelihood L: test if consistent with certain Δm_s



First Measurement at DØ - March 2006
PRL 97, 021802 (2006):

$$17\ \text{ps}^{-1} < \Delta m_s < 21\ \text{ps}^{-1}\ (90\%\ \text{C.L.})$$

After Publication

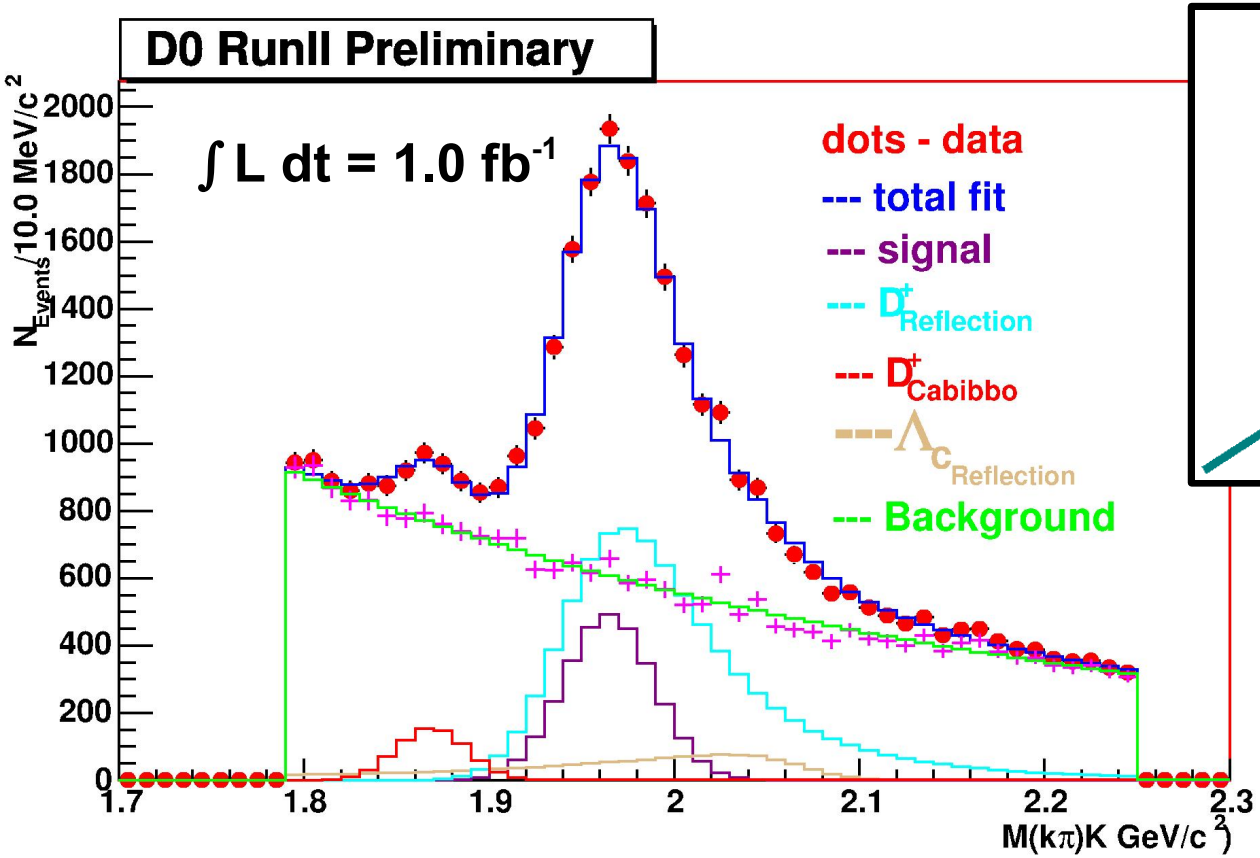
3 more decay channels:

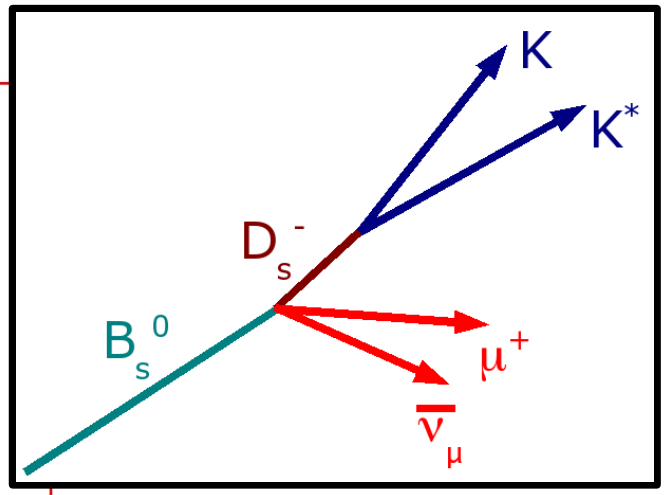
$$B_s \to \mu\nu_\mu D_s(K^* K)$$

$$B_s \to \mu\nu_\mu D_s(K_s^0 K)$$

$$B_s \to e\nu_e D_s(\phi\pi)$$

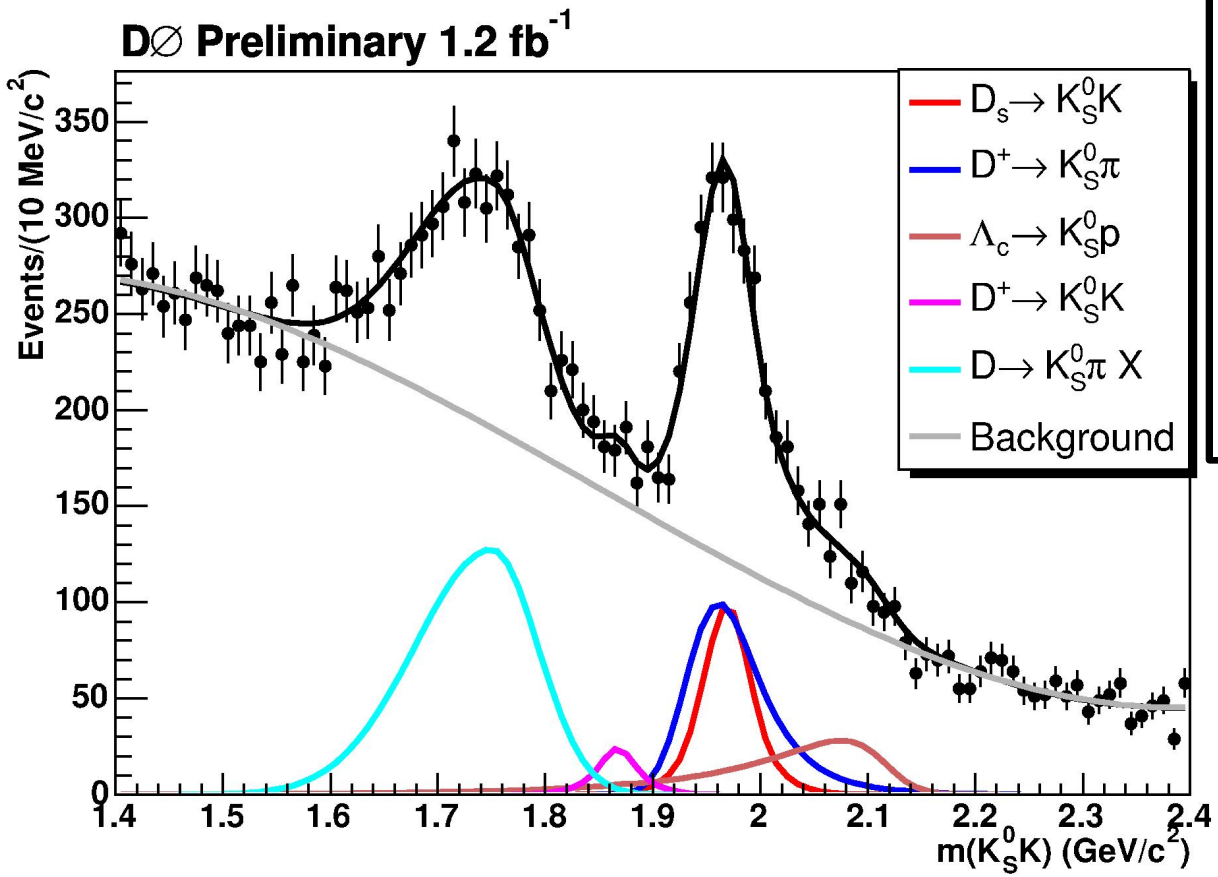
$B_s \to \mu\nu_\mu D_s(K^*K)$

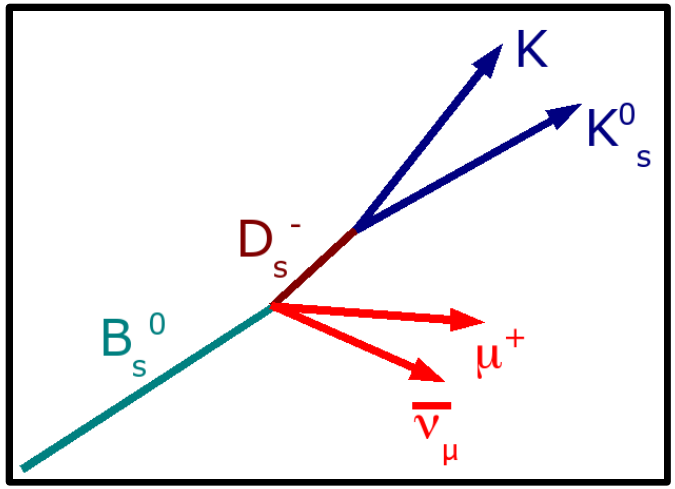




- Technique first used at CDF
- K^* mass cut
- Reflection is directly in signal region
  -> low S/(S+B) ratio
- DØ Note 5172-CONF (2006)

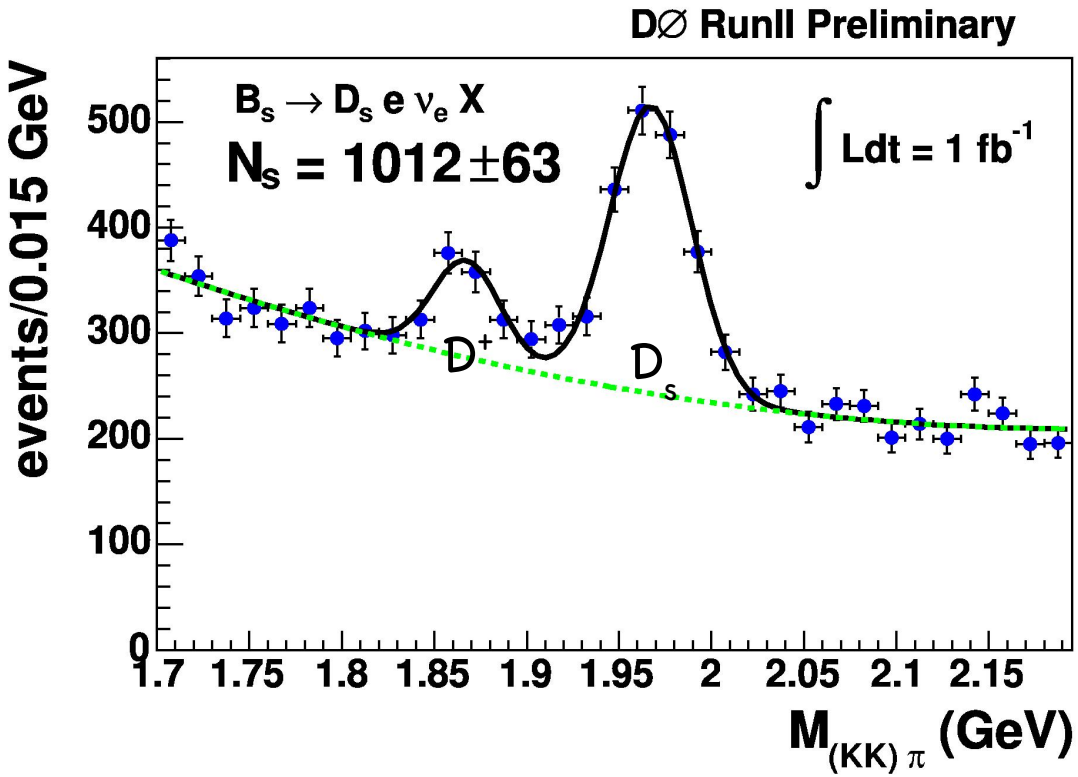
$B_s \to \mu\nu_\mu D_s(K_s^0 K)$

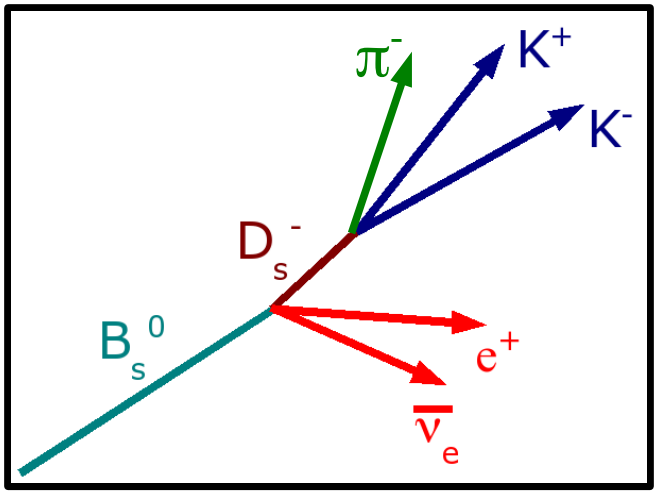




- K_s^0 mass cut
- Overlapping reflection in signal region like in K*K
  -> low S/(S+B) ratio
- DØ Note 5254-CONF (2006)

$B_s \to e\nu_e D_s(\phi\pi)$

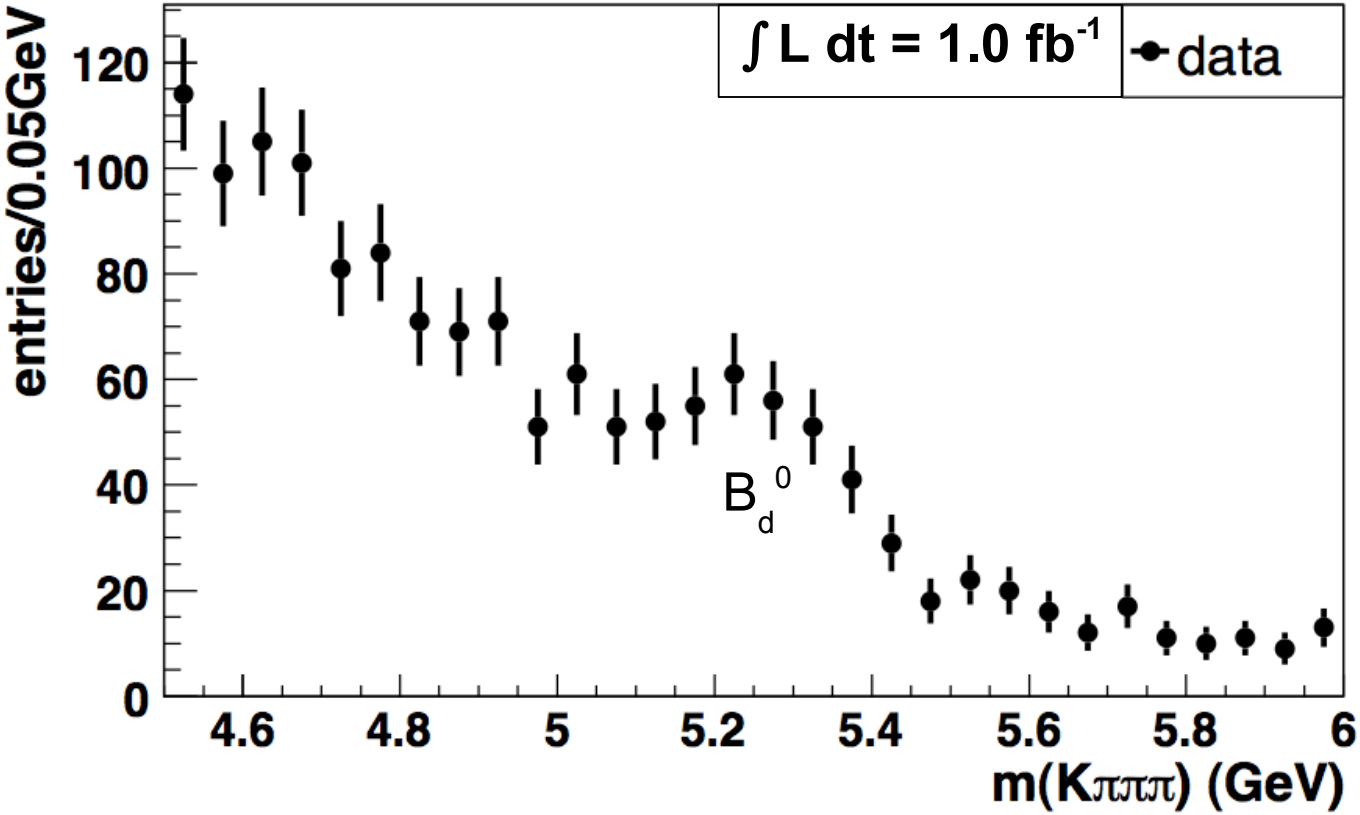




- Hard to trigger: no inclusive single electron trigger with low p_T
  -> Trigger on μ on other side
  -> BUT: every selected event tagged -> $\varepsilon \approx 1$
- εD^2 higher than in $B_s \to \mu\nu_\mu D_s(\phi\pi)$
- DØ Note 5174-CONF (2006)

Selecting Hadronic B_d

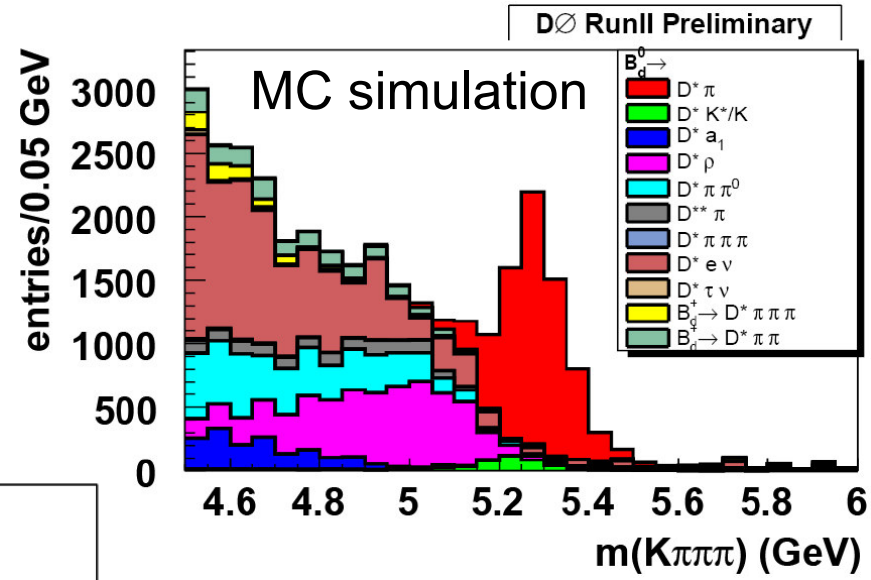
- Fully reconstructable events in hadronic modes
- Same trigger signatures like in $B_s \to e\nu_e D_s(\phi\pi)$
  -> Trigger on μ on other side

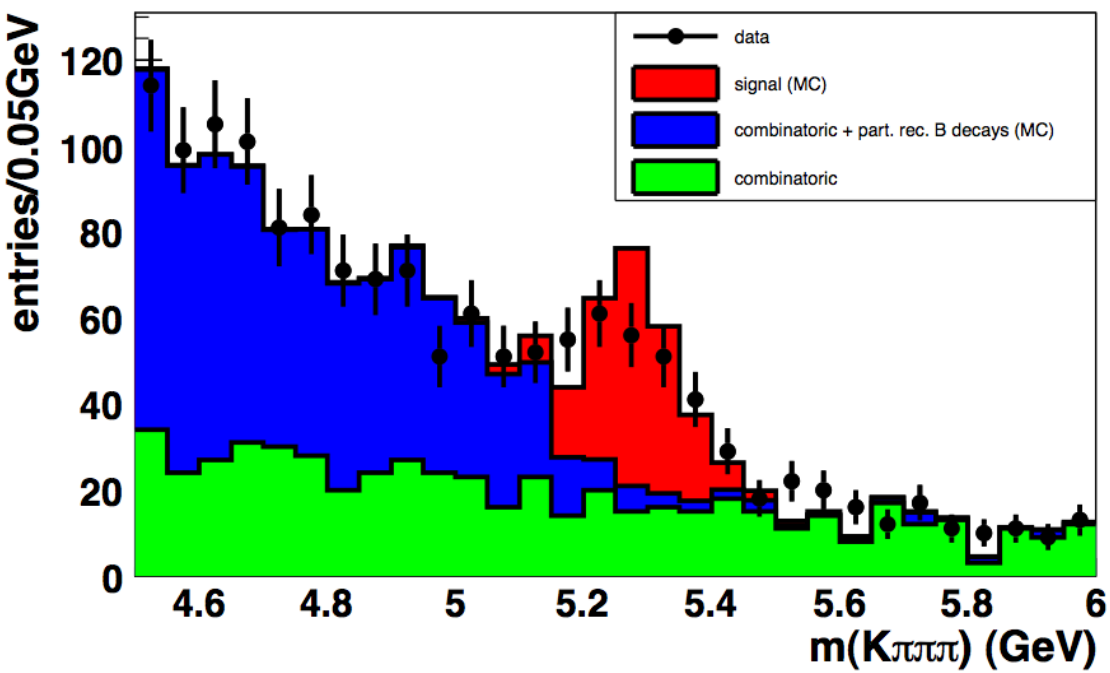


Already able to select B_d candidates

Selecting Hadronic B_d

- Extensive MC studies to understand background
- $\int L\, dt = 1.0\ fb^{-1}$





DØ-Note 5161 (2006)

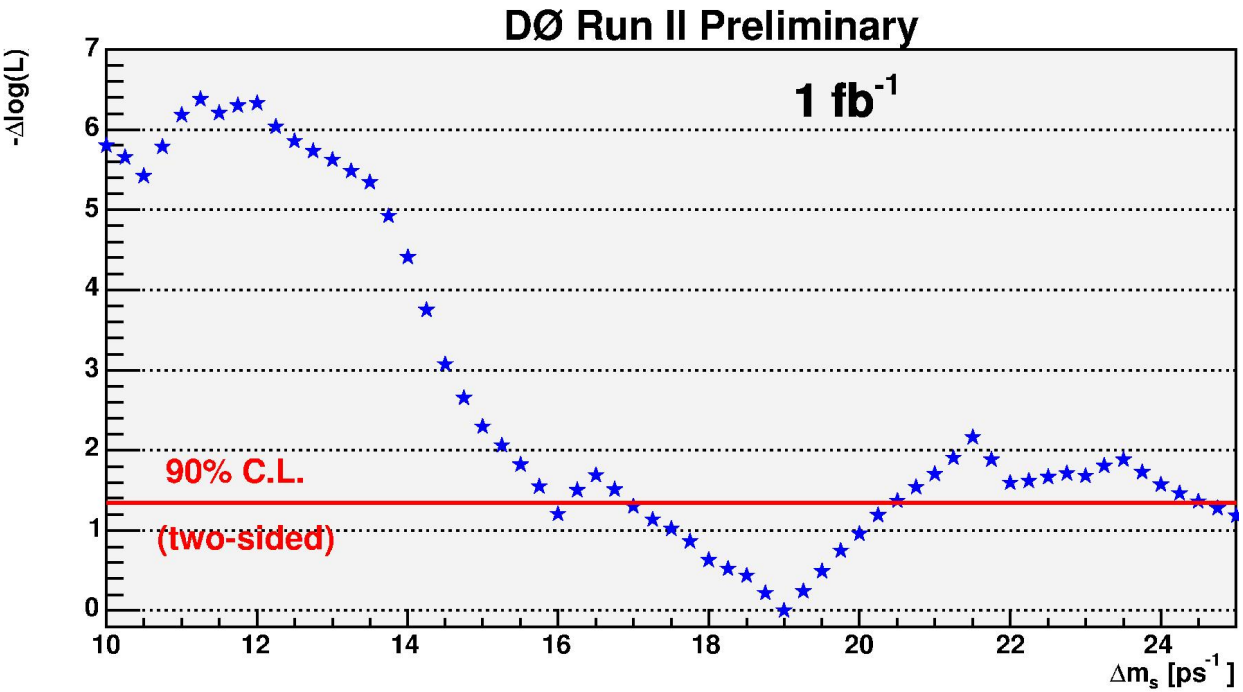
Overview: Selected Samples

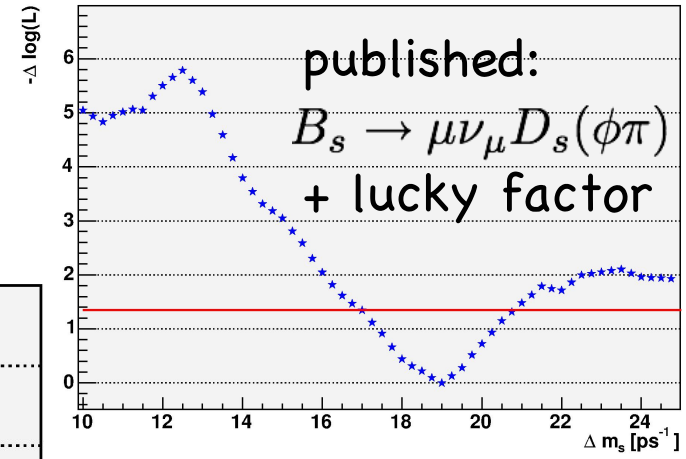
	Tagged	S/N	Limit
$B_s \to e\nu_e D_s(\phi\pi)$	1012 ± 63	0.5	$\Delta m_s > 7.9\ ps^{-1}$ (95% CL)
$B_s \to \mu\nu_\mu D_s(K^*K)$	2997 ± 146	0.16	$\Delta m_s > 9.3\ ps^{-1}$ (95% CL)
$B_s \to \mu\nu_\mu D_s(K_s^0 K)$	593 ± 67	0.17	$\Delta m_s > 1.09\ ps^{-1}$ (95% CL)
$B_s \to \mu\nu_\mu D_s(\phi\pi)$	5601 ± 102	2.2	$17 < \Delta m_s < 21\ ps^{-1}$ (90% CL)

Combination all decay modes

$B_s \to \mu\nu_\mu D_s(\phi\pi)$ $\quad$ $B_s \to \mu\nu_\mu D_s(K^*K)$

$B_s \to \mu\nu_\mu D_s(K_s^0 K)$ $\quad$ $B_s \to e\nu_e D_s(\phi\pi)$



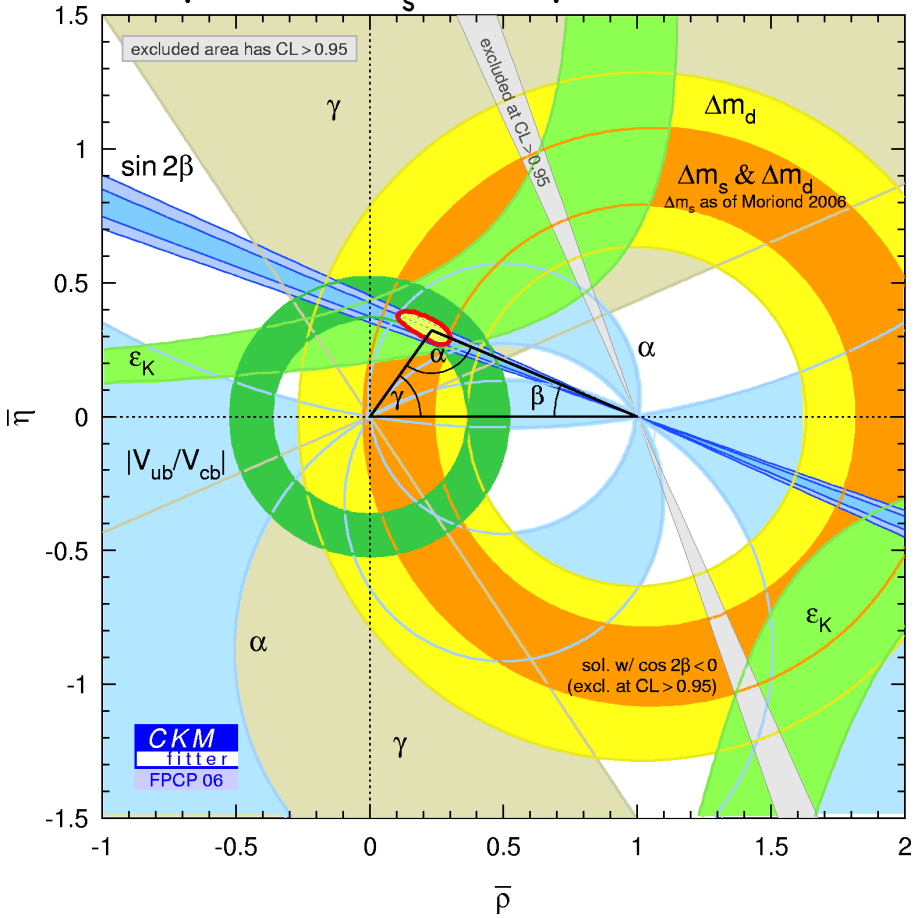


$$17\ \text{ps}^{-1} < \Delta m_s < 21\ \text{ps}^{-1}\ (90\%\ \text{C.L.})$$

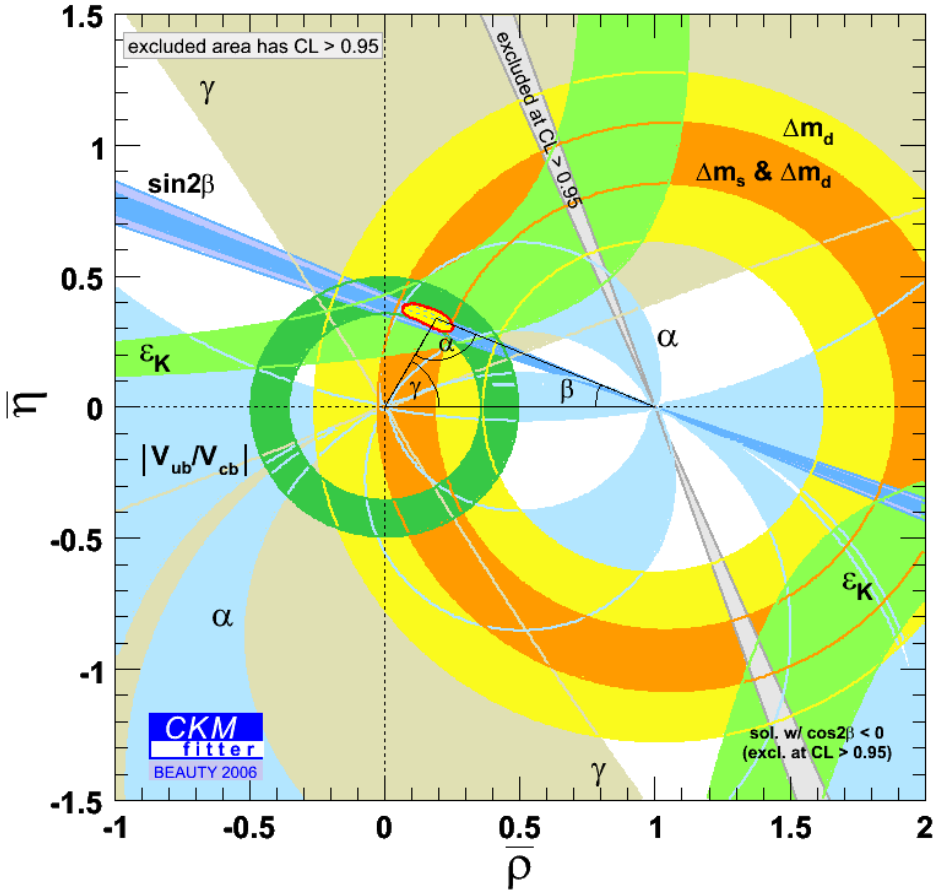
Impact on Unitarity Triangle

DØ (Moriond 2006)

$17\ ps^{-1} < \Delta m_s < 21\ ps^{-1}$ (95% C.L.)



DØ + CDF



Huge impact on UT from DØ Moriond results

Now dominated by theoretical uncertainties

Conclusion and Outlook

- DØ: first experiment gave two boundaries limit
  $\Rightarrow$ no indication for new physics from Δm_s
  - Published results for $B_s \to \mu\nu_\mu D_s(\phi\pi)$
  - Preliminary results for three more channels:

$$B_s \to e\nu_e D_s(\phi\pi)$$

$$B_s \to \mu\nu_\mu D_s(K^*K)$$

$$B_s \to \mu\nu_\mu D_s(K_s^0 K)$$

$$\boxed{17\ \mathrm{ps}^{-1} < \Delta m_s < 21\ \mathrm{ps}^{-1}\ (90\%\ \mathrm{C.L.})}$$

- B_d mixing in good agreement with world average
- Already selected hadronic B_d signal

- Extend analysis to RunIIb data:
  - More data: already have 2 fb^{-1} on tape
  - Include more channels

Backup

B_s Mixing

Want to measure CKM matrix element $|V_{td}|$

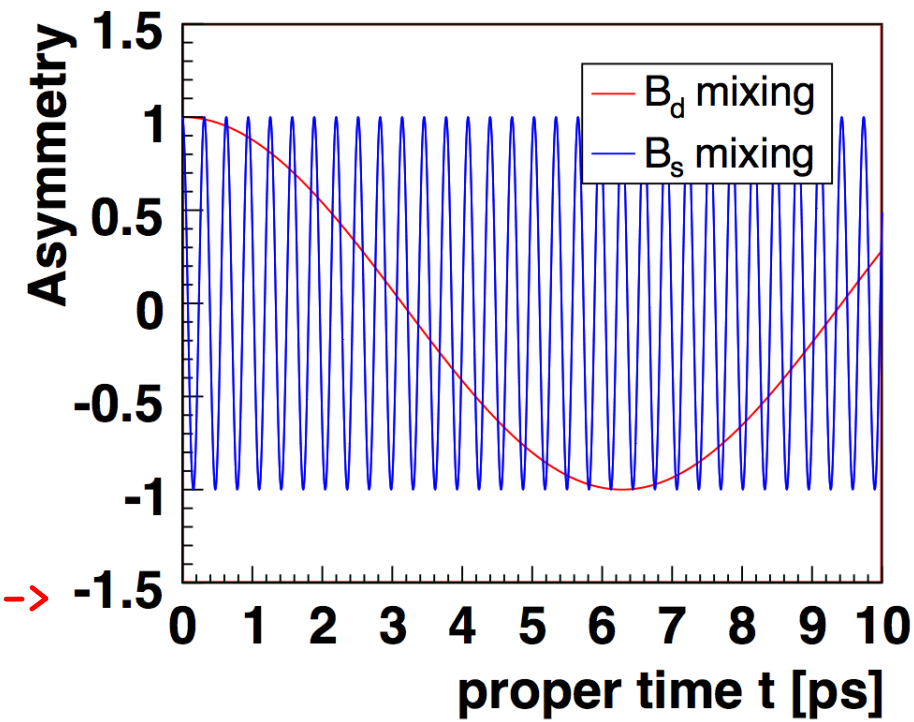
through measurement of mass difference:

$$\Delta m_d \propto m_B B_{B_d} f_{B_d} |V_{tb}^* V_{td}|^2 \cdot (\text{hadr. terms})$$

Precise measurement of $\Delta m_d = (0.507 \pm 0.005)\ ps^{-1}$ (PDG) at BaBar and Belle

- BUT: hadronic correction terms
- TRICK: calculate ratio to reduce uncertainties

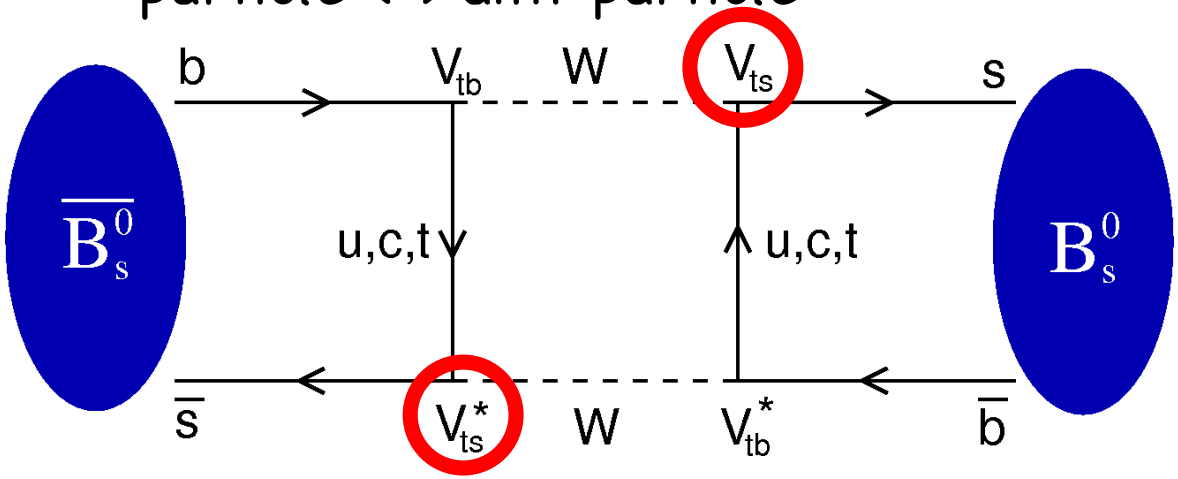
$$\frac{\Delta m_s}{\Delta m_d} \alpha \frac{|V_{ts}|^2}{|V_{td}|^2}$$

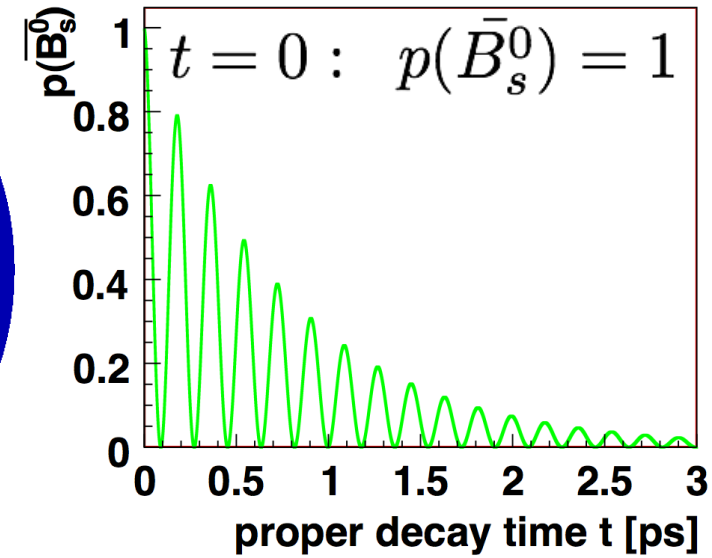


Challenge: Higher oscillation frequency ->

B-Mixing

particle <-> anti-particle





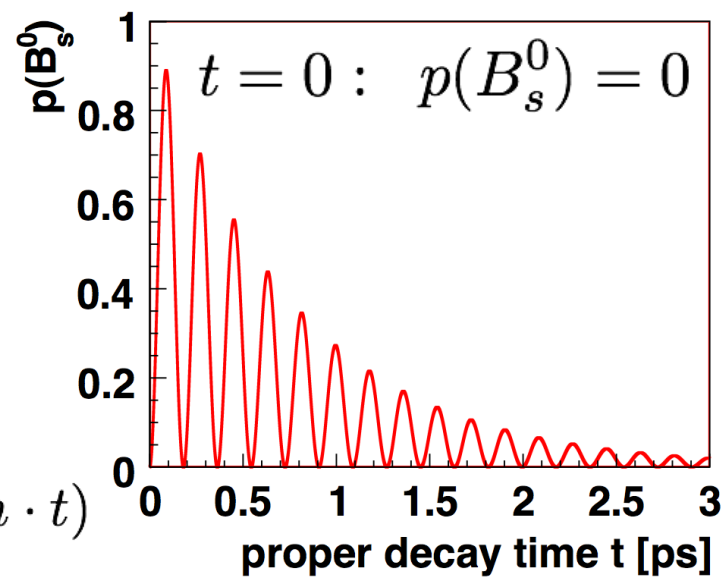
$|B_H\rangle = p\,|\overline{B}^0\rangle + q\,|B^0\rangle$

$|B_L\rangle = p\,|\overline{B}^0\rangle - q\,|B^0\rangle$

with $|p|^2 + |q|^2 = 1$

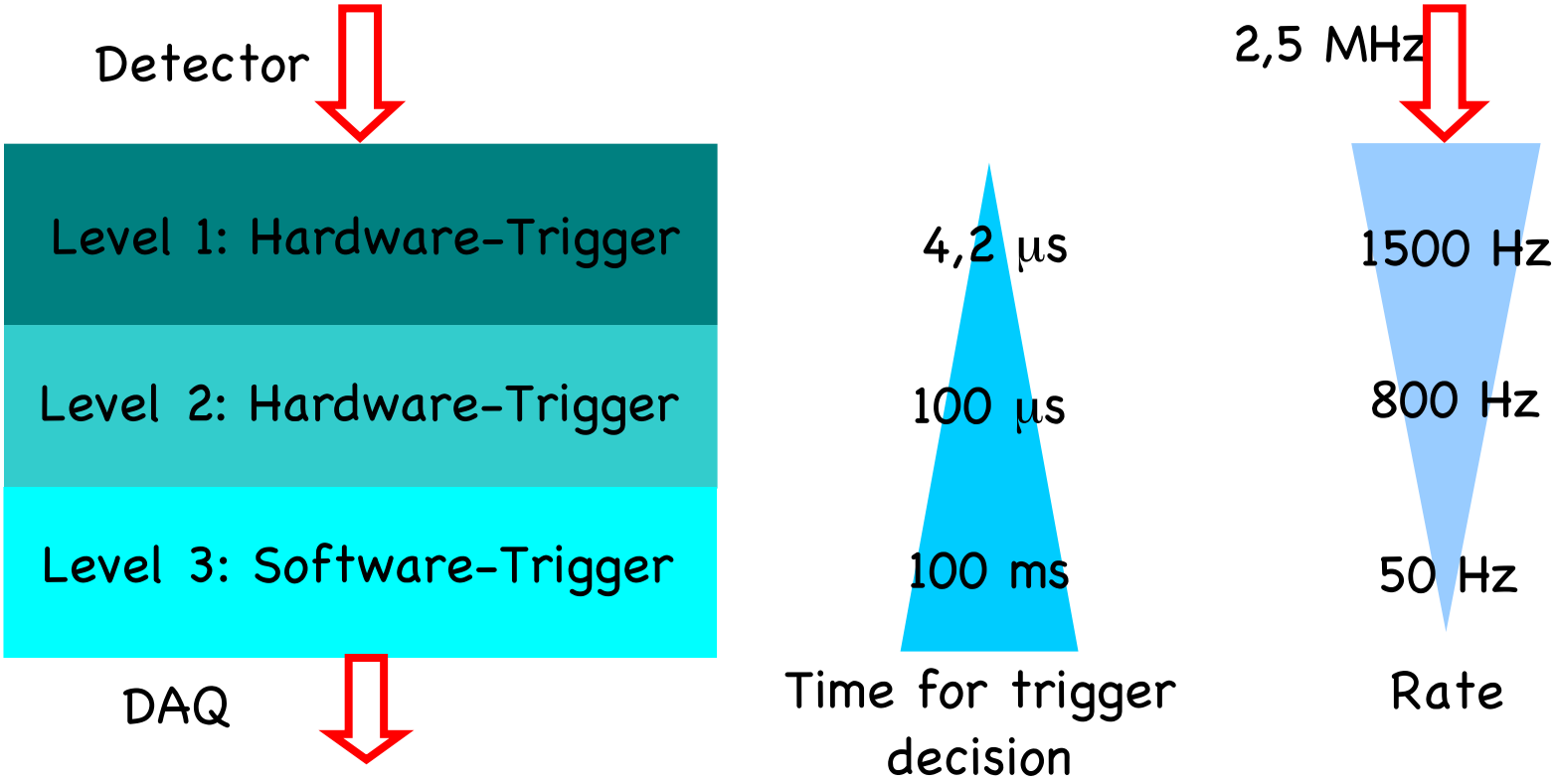
mass difference $\Delta m = m_H - m_L$

$\Rightarrow$ Oscillation of B-Mesons



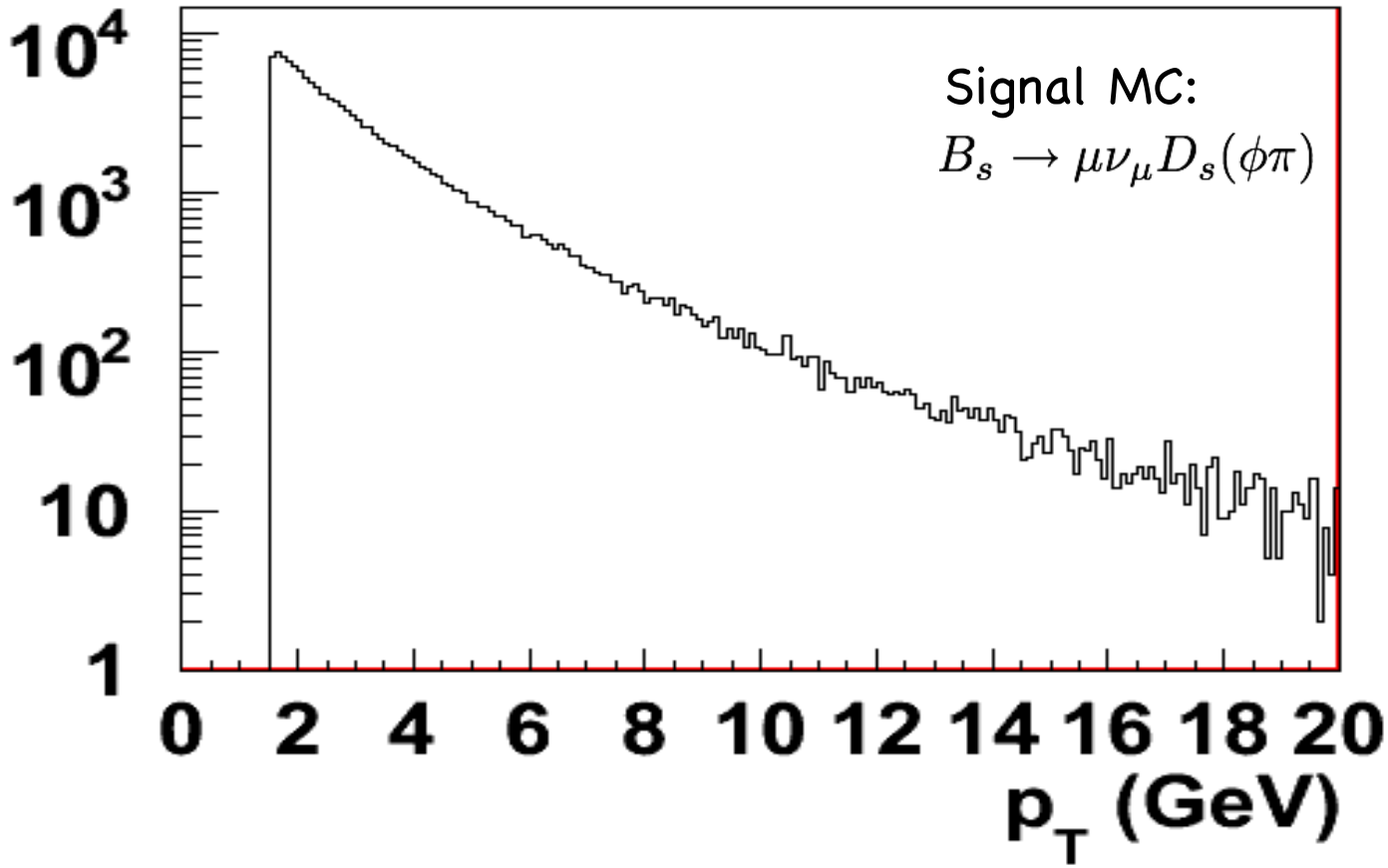
$$A(t) = \frac{N_{\text{unoscillated}}(t) - N_{\text{oscillated}}(t)}{N_{\text{unoscillated}}(t) + N_{\text{oscillated}}(t)} \propto \cos(\Delta m \cdot t)$$

Trigger-System



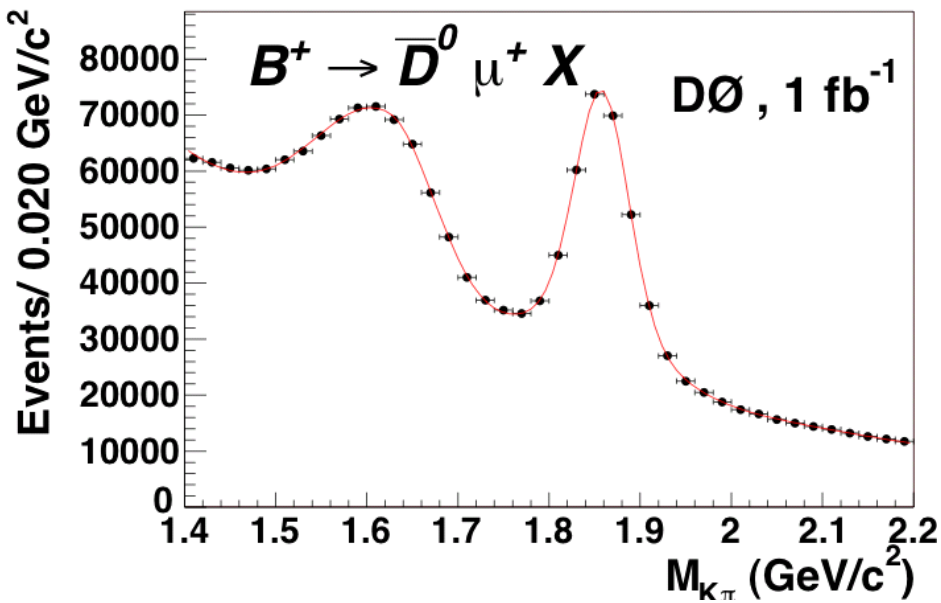
Compare: at luminosity: $60*10^{30}$ $cm^{-2}s^{-1}$
→μ-rate from b-pair-production: ≈ 17 kHz

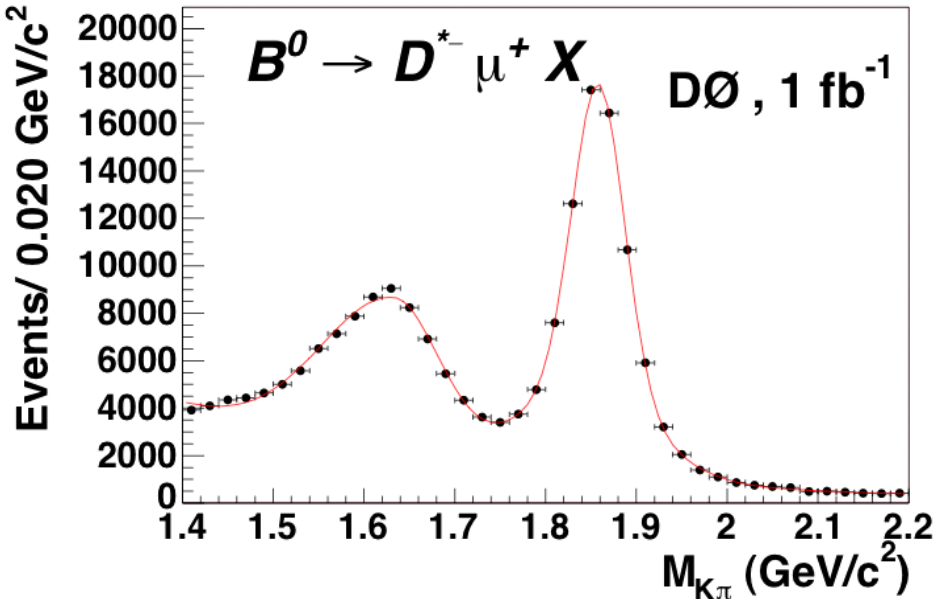
Level 1 Muon Trigger



Raising muon p_T threshold will significantly cut signal

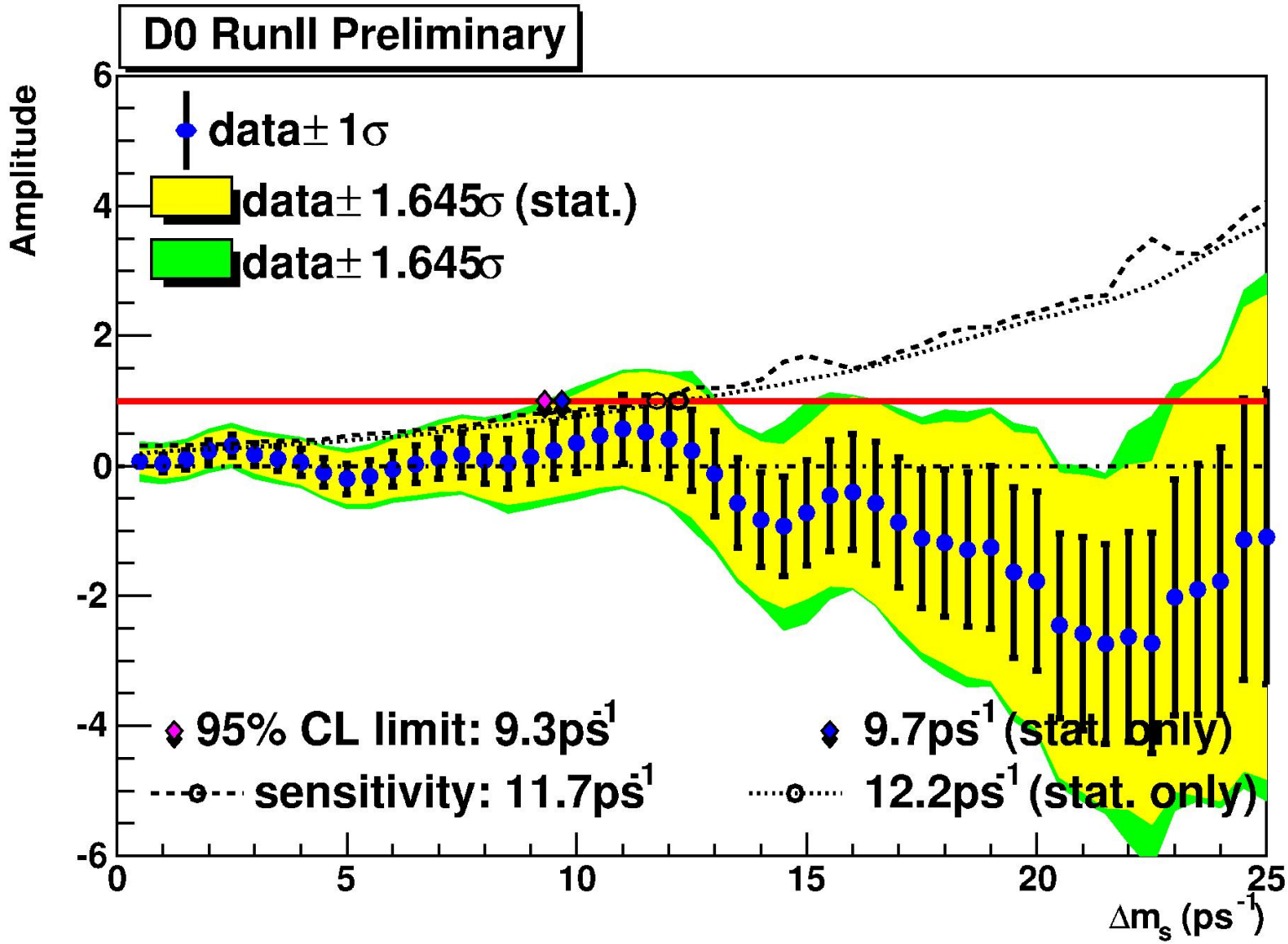
B_d Mixing


$B^+ \to \overline{D}^0 \mu^+ X$
DØ , 1 fb^{-1}
Events/ 0.020 GeV/c^2
80000
70000
60000
50000
40000
30000
20000
10000
0
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
$M_{K\pi}$ (GeV/c^2)


$B^0 \to D^{*-} \mu^+ X$
DØ , 1 fb^{-1}
Events/ 0.020 GeV/c^2
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
$M_{K\pi}$ (GeV/c^2)

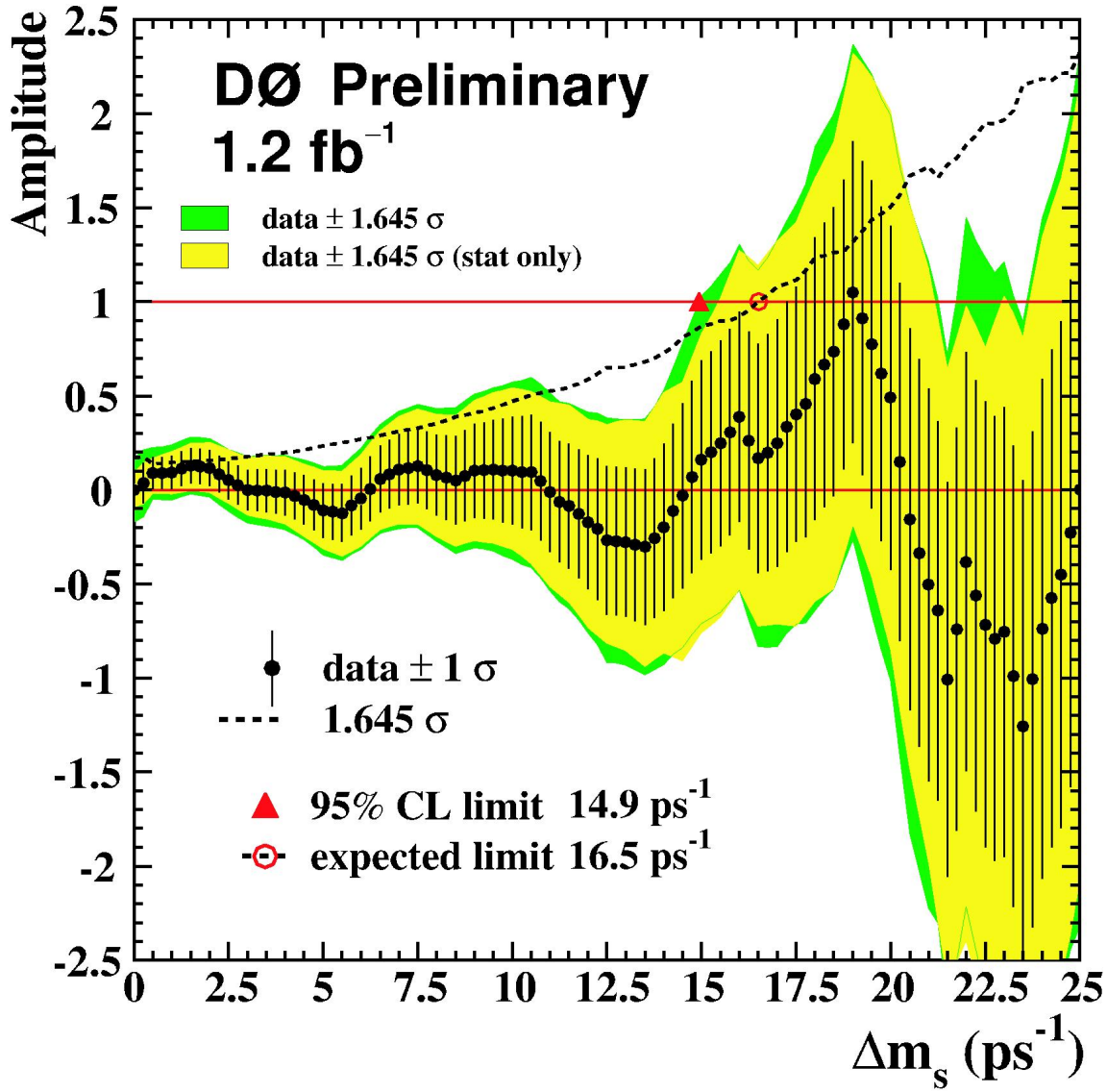
Backup

$$B_s \to \mu\nu_\mu D_s(K^*K)$$



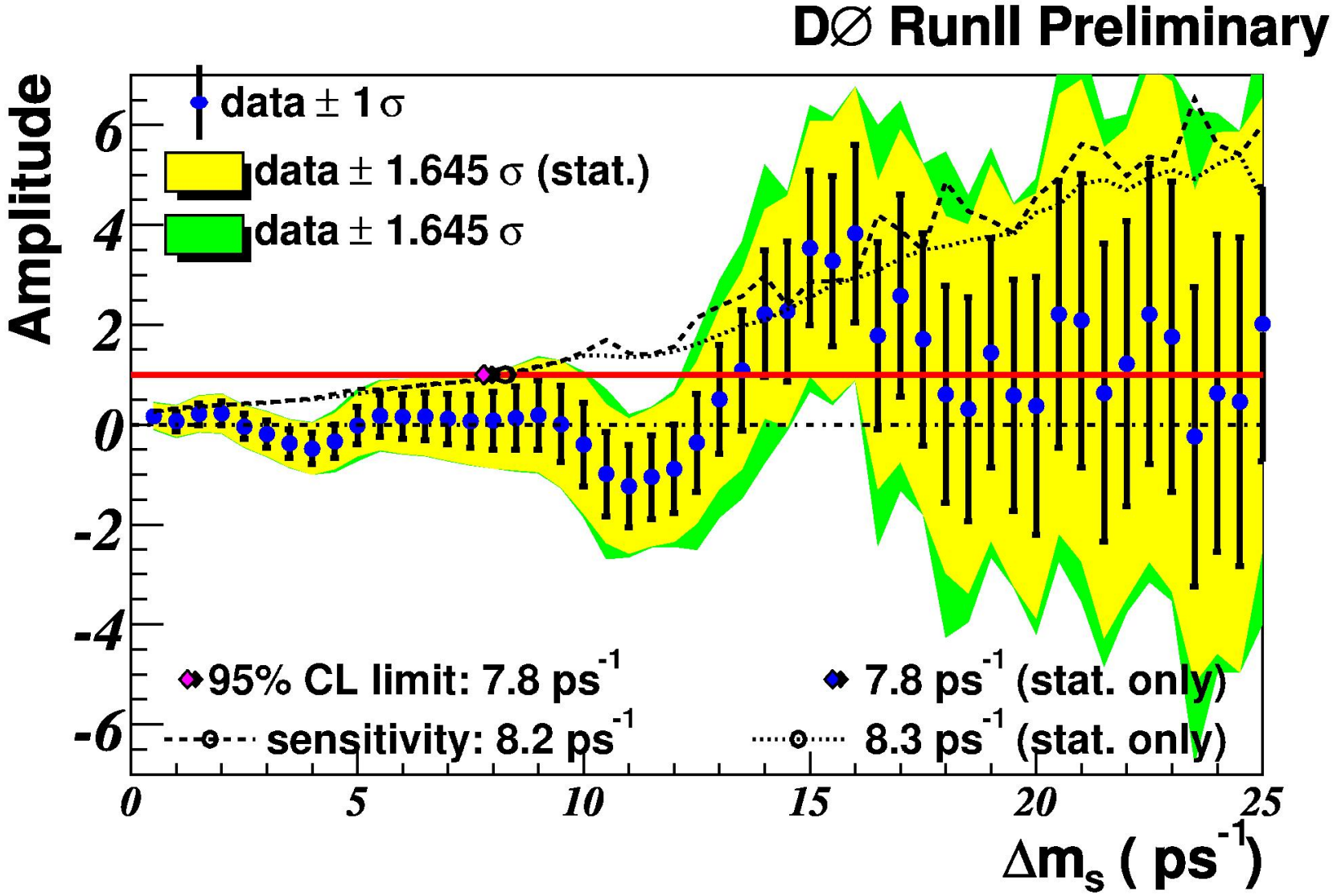
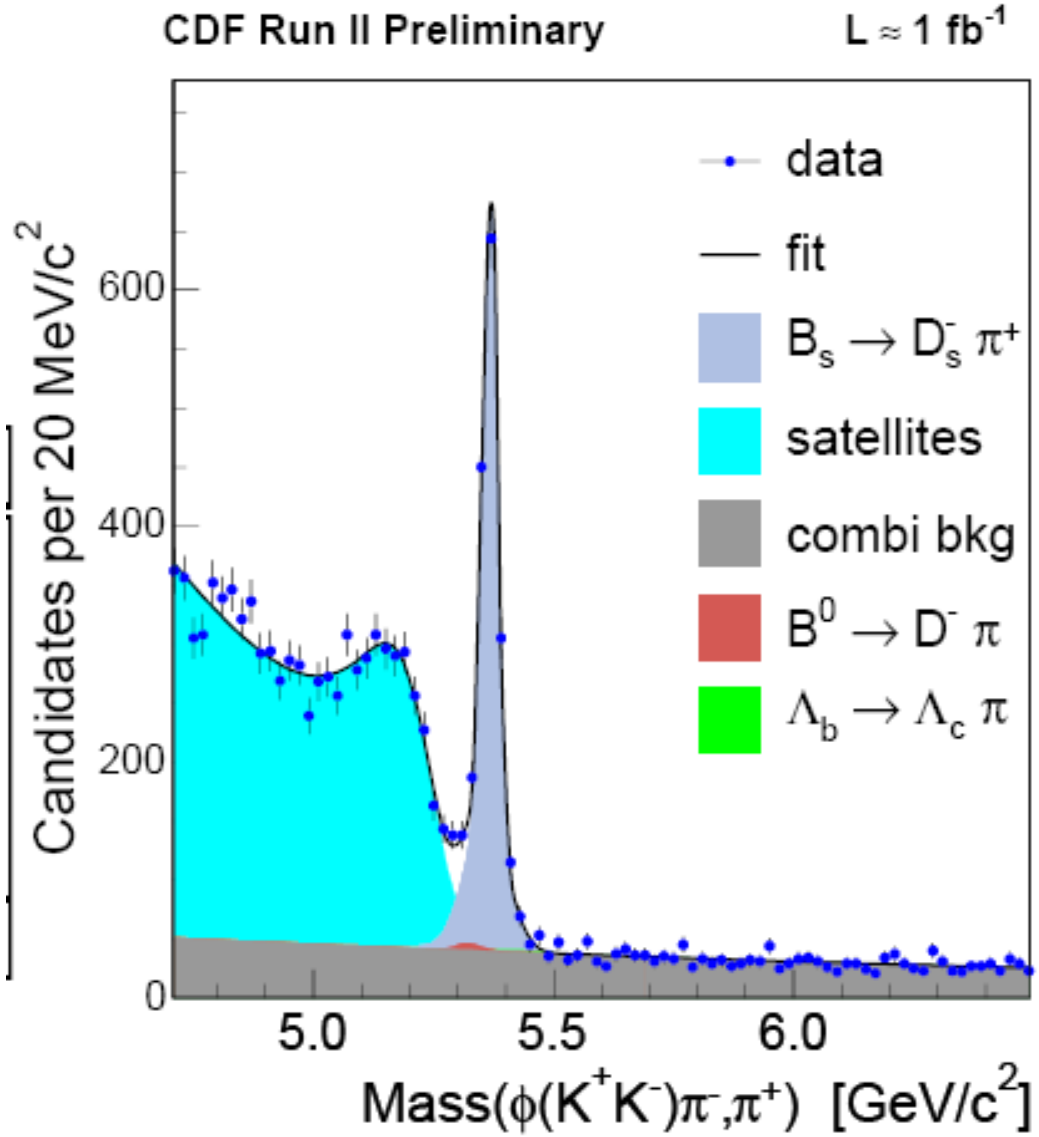
Backup

$$B_s \to \mu\nu_\mu D_s(K_s^0 K)$$



Backup

$$B_s \to e\nu_e D_s(\phi\pi)$$



CDF Hadronic Signal