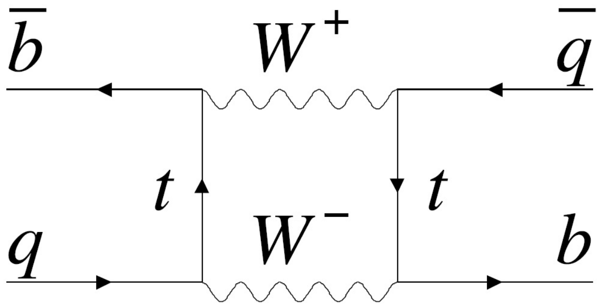
B_s Mixing Studies at DØ

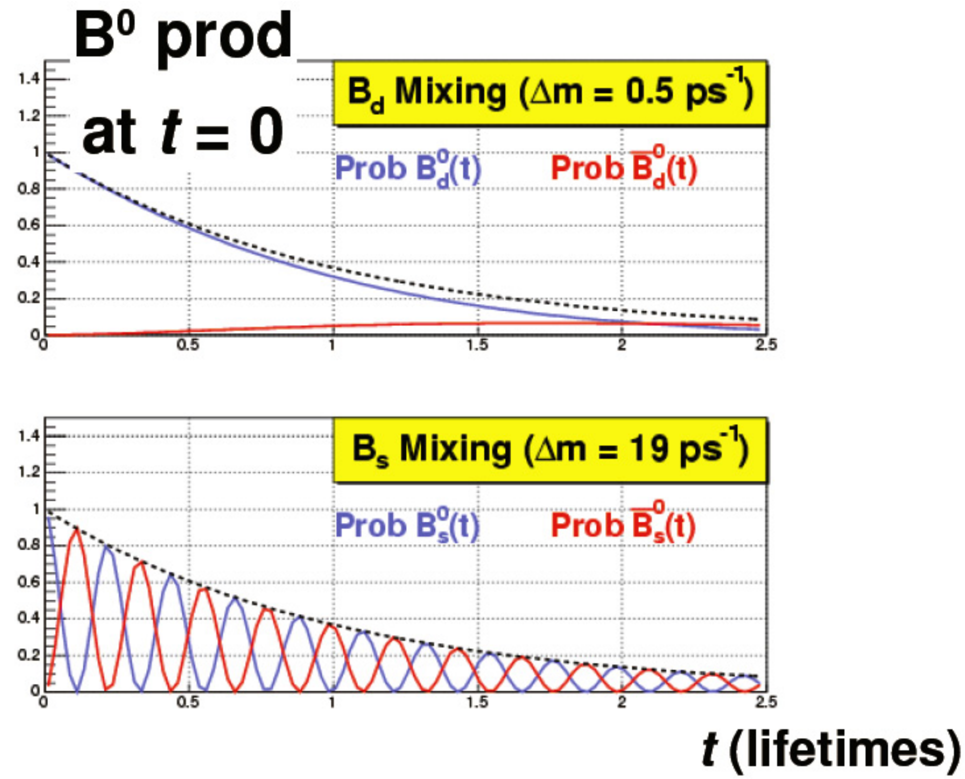
Peter Tamburello
for the
DØ Collaboration

Beauty 2006, Oxford

$B_s^0 \to \mu^+ D_s^- X, \quad D_s^- \to \phi\pi^-$		(published)
$B_s^0 \to \mu^+ D_s^- X, \quad D_s^- \to K^{*0} K^-$		(preliminary)
$B_s^0 \to e^+ D_s^- X, \quad D_s^- \to \phi\pi^-$		(preliminary)
Combined results		(preliminary)

B–$\overline{B}$ Mixing





- Initial state B_q^0 decays as a $B_q^0/\overline{B}_q^0$ with $p(t) \simeq \frac{\Gamma}{2}e^{-\Gamma t}[1 \pm \cos(\Delta m_q t)]$
- Many measurement for B_d, $\Delta m_d = 0.507 \pm 0.005\ \text{ps}^{-1}$ (RPP 2006)
- In SM expect $\Delta m_s = 20.9^{+4.5}_{-4.2}$ from indirect global CKM fits (RPP 2004)
- End 2005 $\Delta m_s > 16.6\ \text{ps}^{-1}$ 95% C.L. (hep-ex/0603003)

- March 2006 $17 < \Delta m_s < 21$ ps^{-1} from DØ (PRL 97, 021802, 2006)
- Followed by CDF results including fully reconstructed modes (following talk)
- Measurement of Δm_s constrains V_{td} and CKM unitary triangle

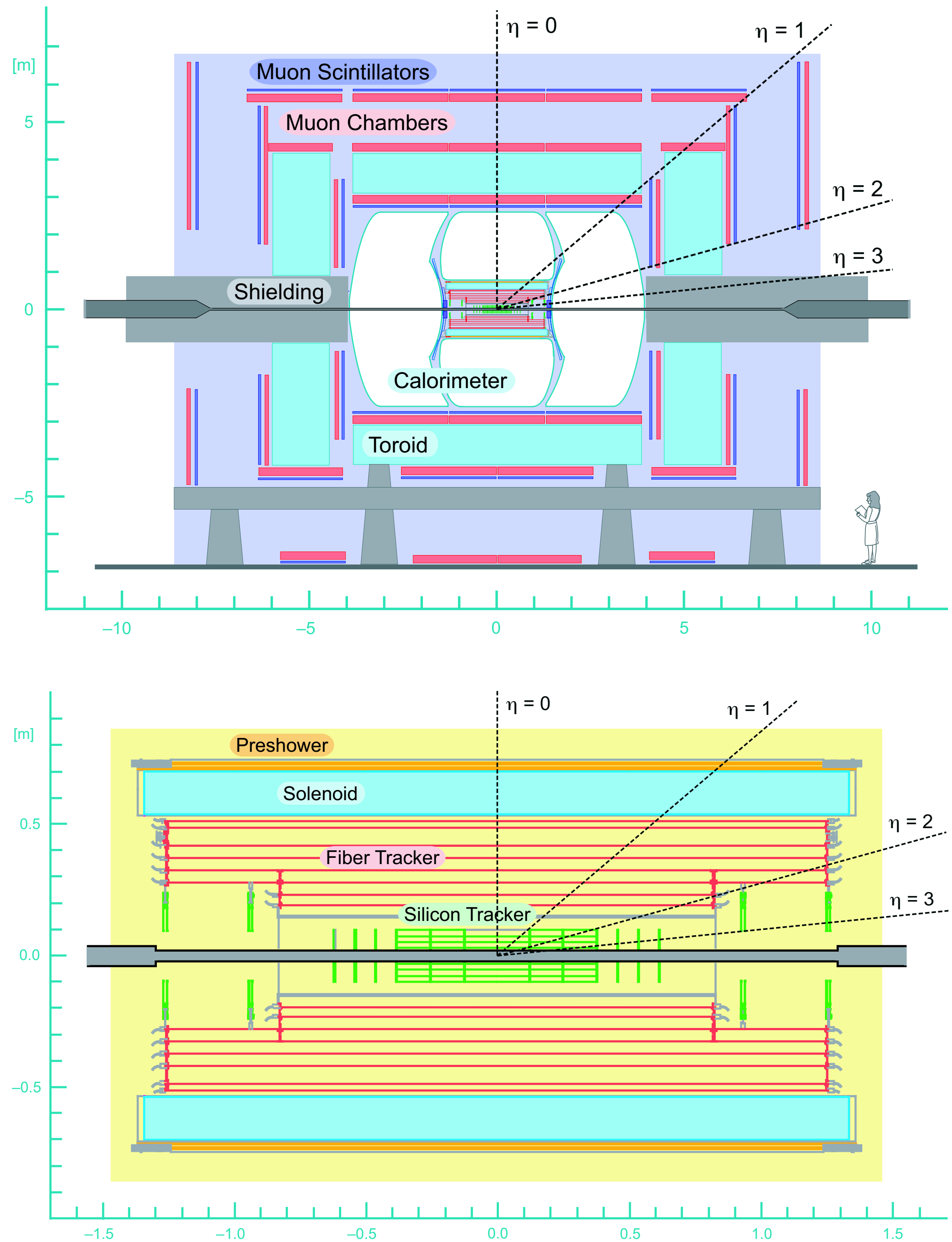
$$\frac{\Delta m_s}{\Delta m_d} = \frac{m(B_s^0)}{m(B_d^0)}\xi^2|\frac{V_{ts}}{V_{td}}|^2$$

$\xi = 1.21 \pm 0.04^{+0.04}_{-0.01}$ from lattice QCD (RPP 2006)

- Sensitive to new physics

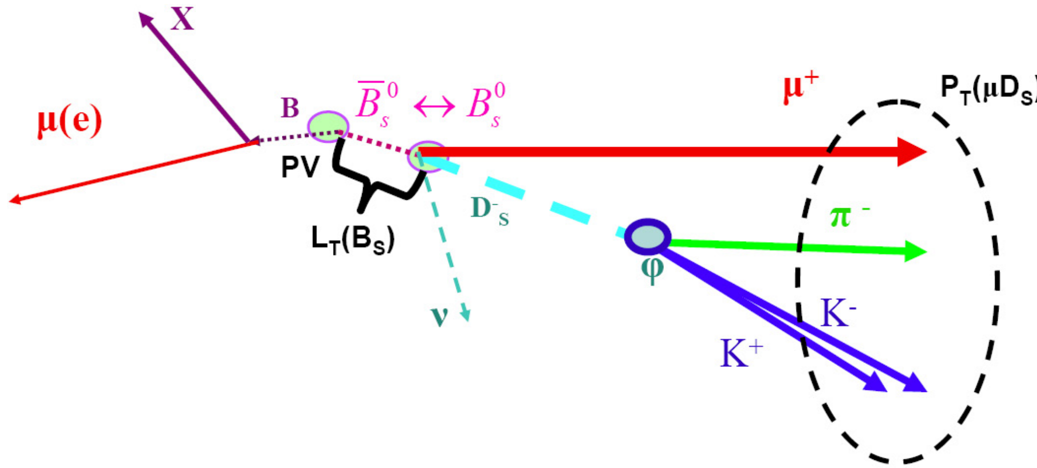
The DØ Detector

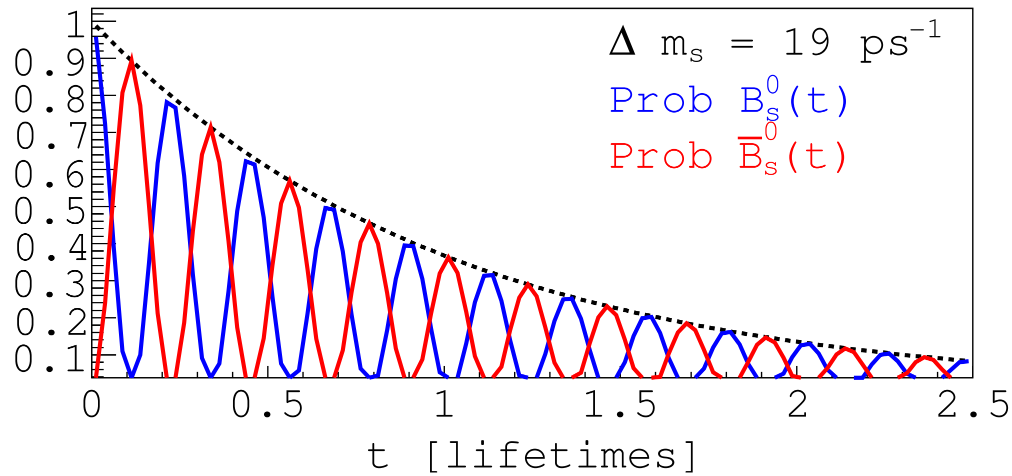
- Muon system
  - low background
  - high coverage
- Calorimeter
  - finely segmented
  - hermetic
- Central tracking
  - silicon
  - fibers
  - 2T solenoid



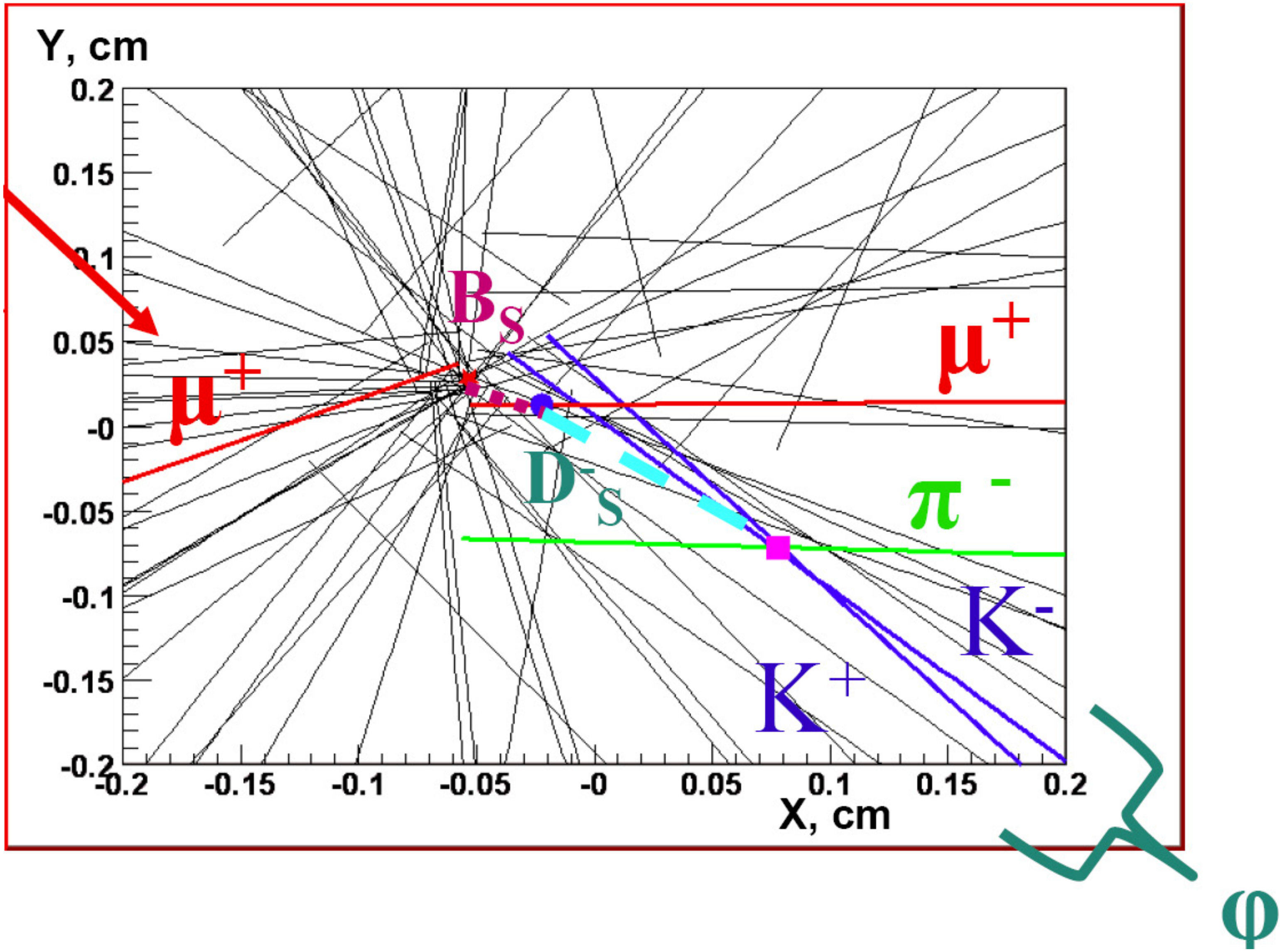
Strategy

- Identify $B_s \to l^+ D_s^- X$
- Charge of l indicates B_s flavor at decay time
- Decay distance L_T reflects lifetime
- B-hadron flavor on opposite side indicates B_s flavor at production time
- Discern oscillations and measure frequency Δm_s



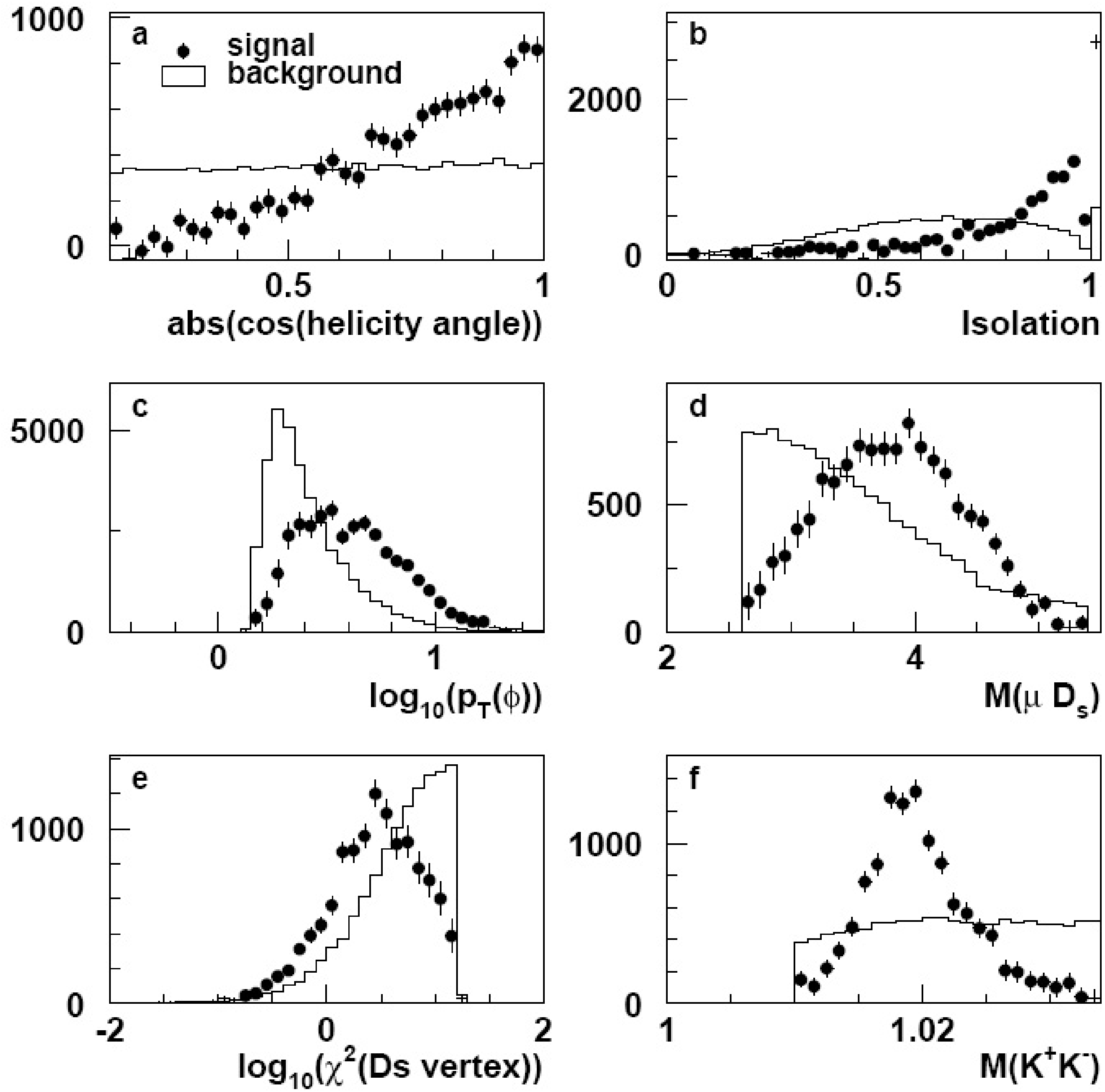


Reconstructed $B_s \to \mu^+ D_s^- X,\ D_s^- \to \phi\pi^-$



Discriminating variables x_i for further background suppression after basic selection cuts

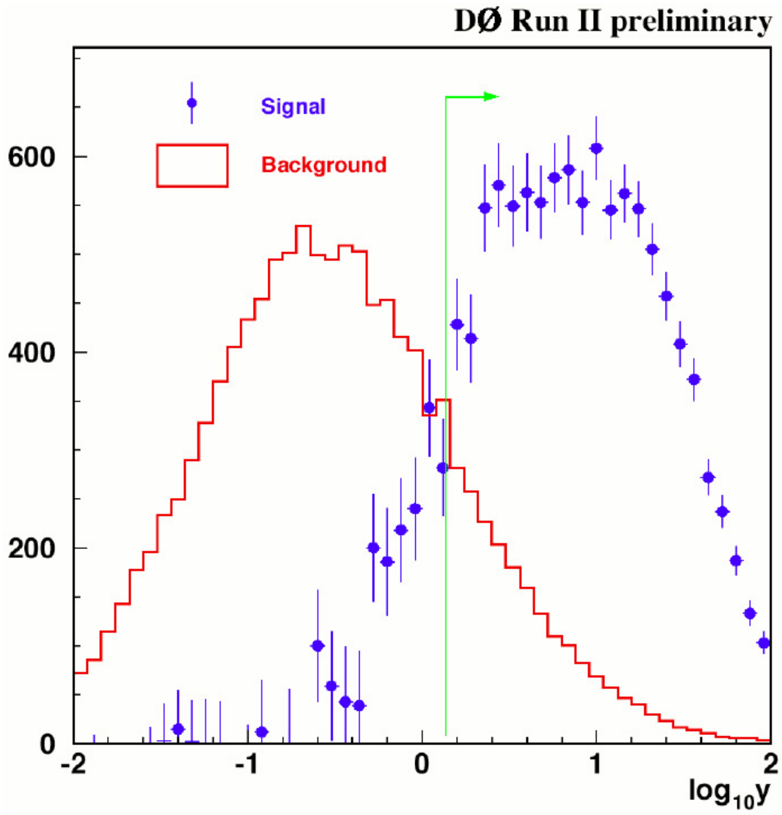
From $\mu^+ D_s^-$, $D_s \to \phi\pi^-$, $\phi \to K^+K^-$ data

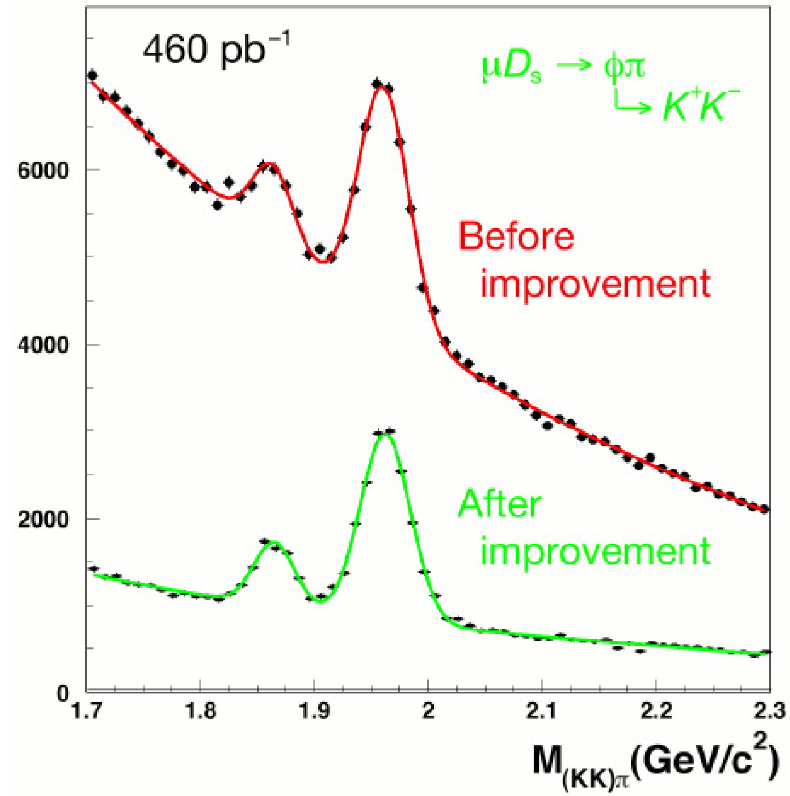


Combined selection variable

- Approximate likelihood ratio $y = \Pi_i \frac{\text{prob}(x_i|\text{signal})}{\text{prob}(x_i|\text{bckgnd})}$

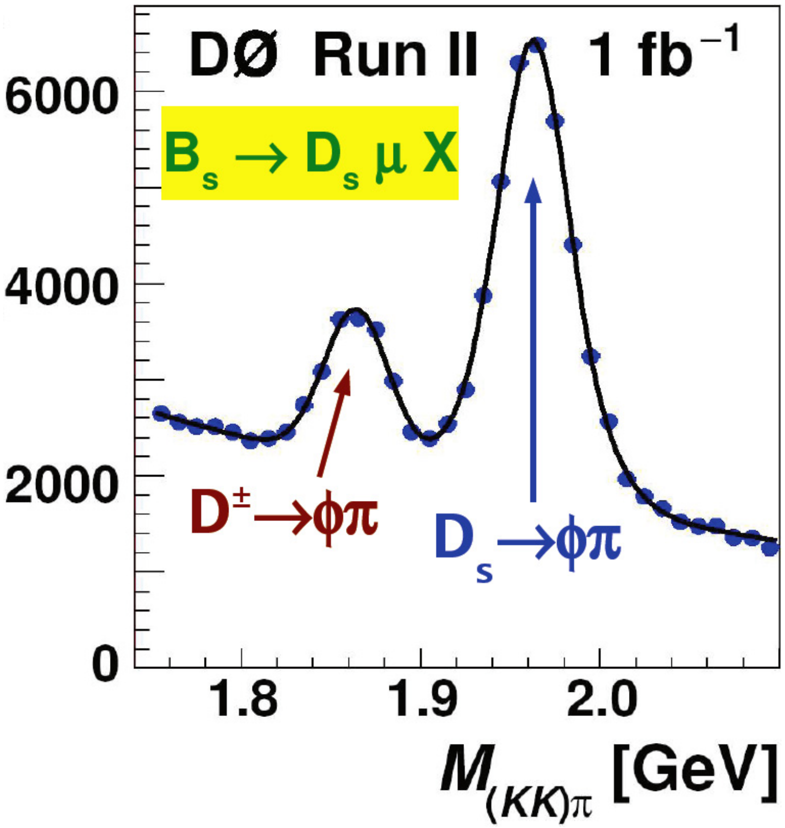
- Threshold optimized for $S/\sqrt{S+B}$



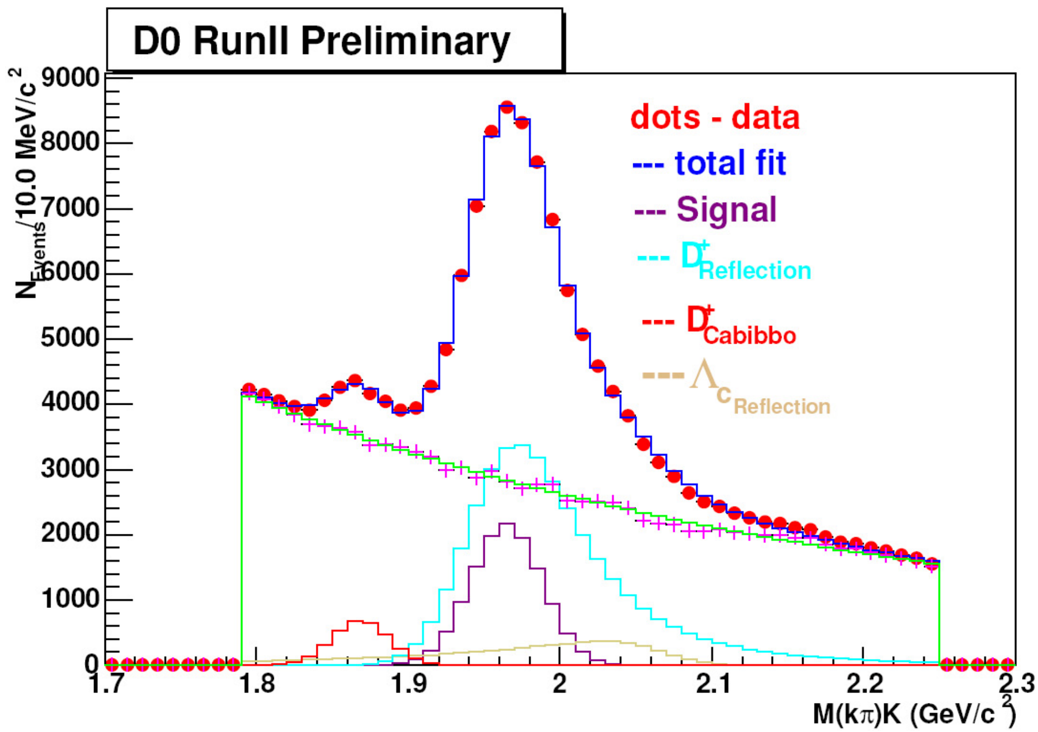


$B_s \to \mu^+ D_s^- X$ pre-tag yields

$26,710 \pm 556\ D_s^- \to \phi\pi^-$

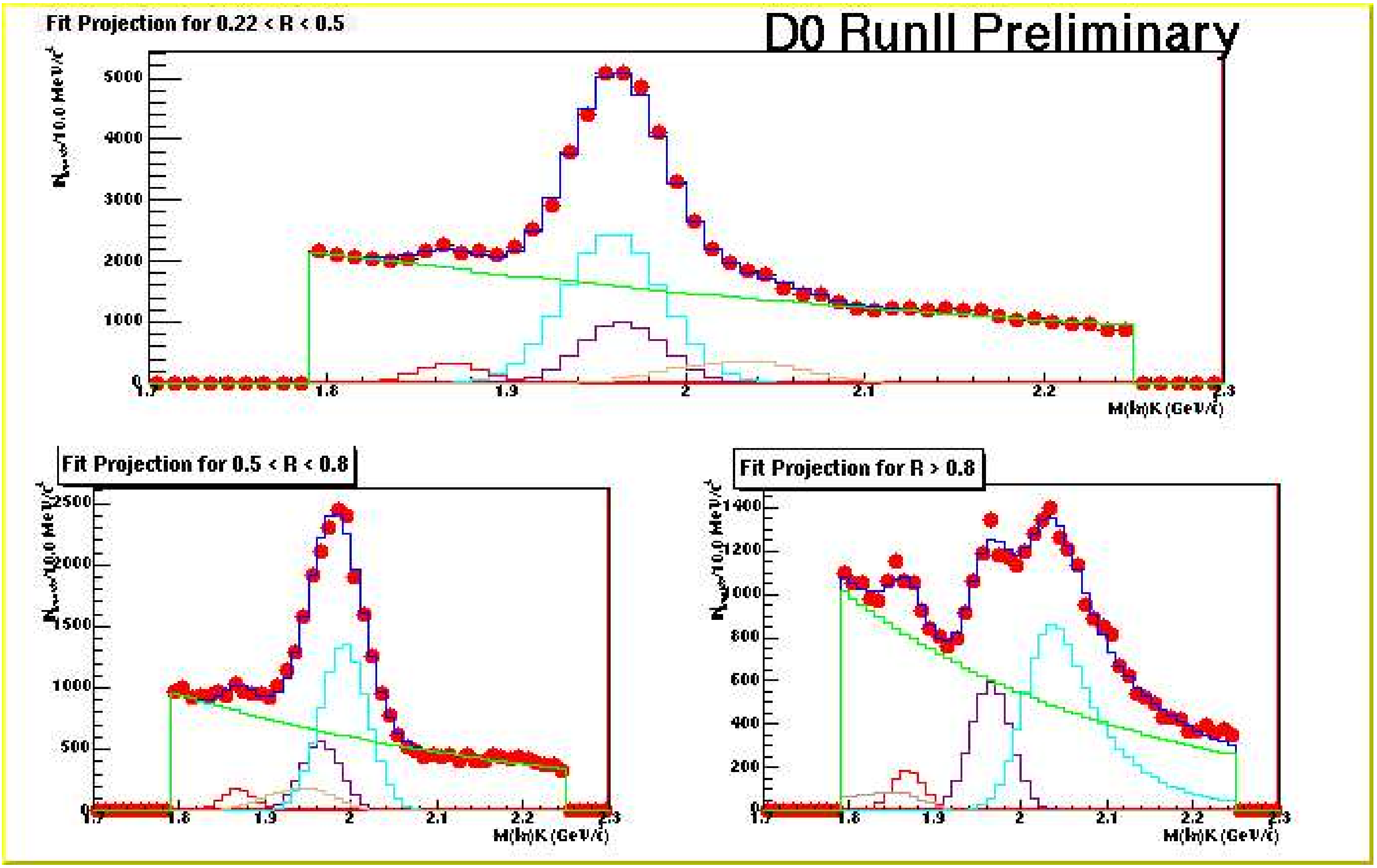


$12,647 \pm 740\ D_s^- \to K^{*0} K^-$



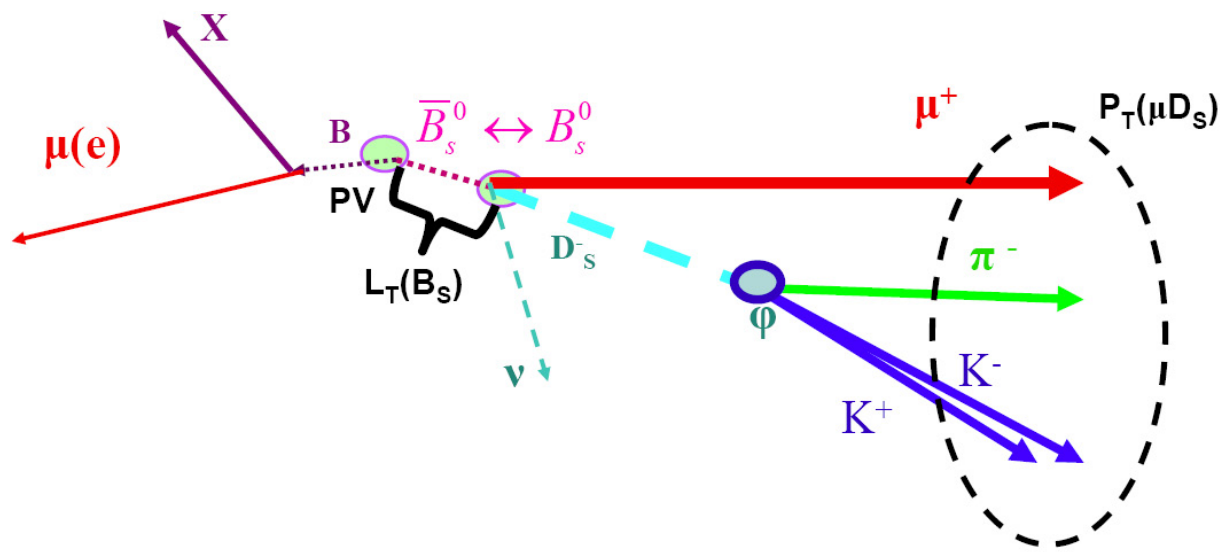
Reflections

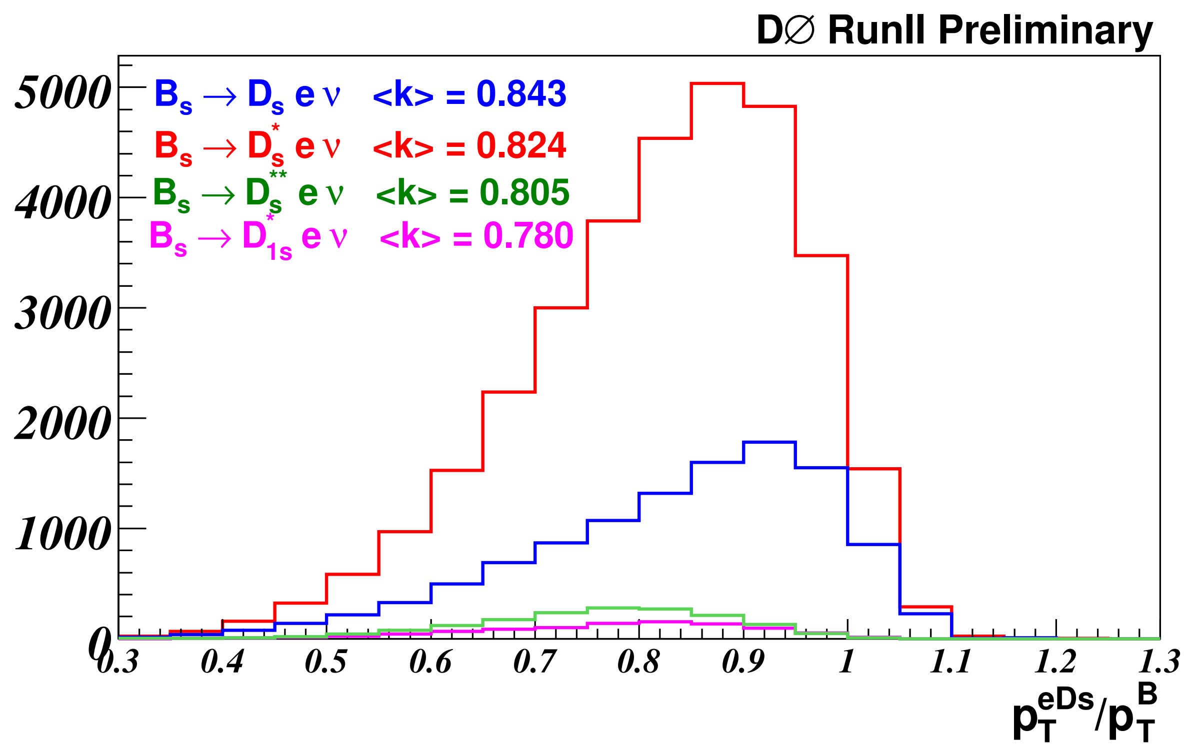
- $D^- \to K^{*0}\pi^-$ shifts onto $D_s^- \to K^{*0}K^-$ peak if π assigned m_K
- Mass shift depends on kinematics, revealing composition



Lifetime

- Decay length L_T
- Proper time $ct = m_{B_s} \frac{L_T}{p_T^{B_s}}$
- But missing ν, and possibly other particles, e.g. $B_s^0 \to \mu^+ \nu D_s^{*-}$, $D_s^{*-} \to D_s^- \gamma$
- Use $$\mathrm{VPDL} = m_{B_s} \frac{\vec{L}_T \cdot \hat{p}_T^{l^+ D_s^-}}{p_T^{l^+ D_s^-}}$$
- $ct = \mathrm{VPDL} \cdot K$





Initial state flavor tag

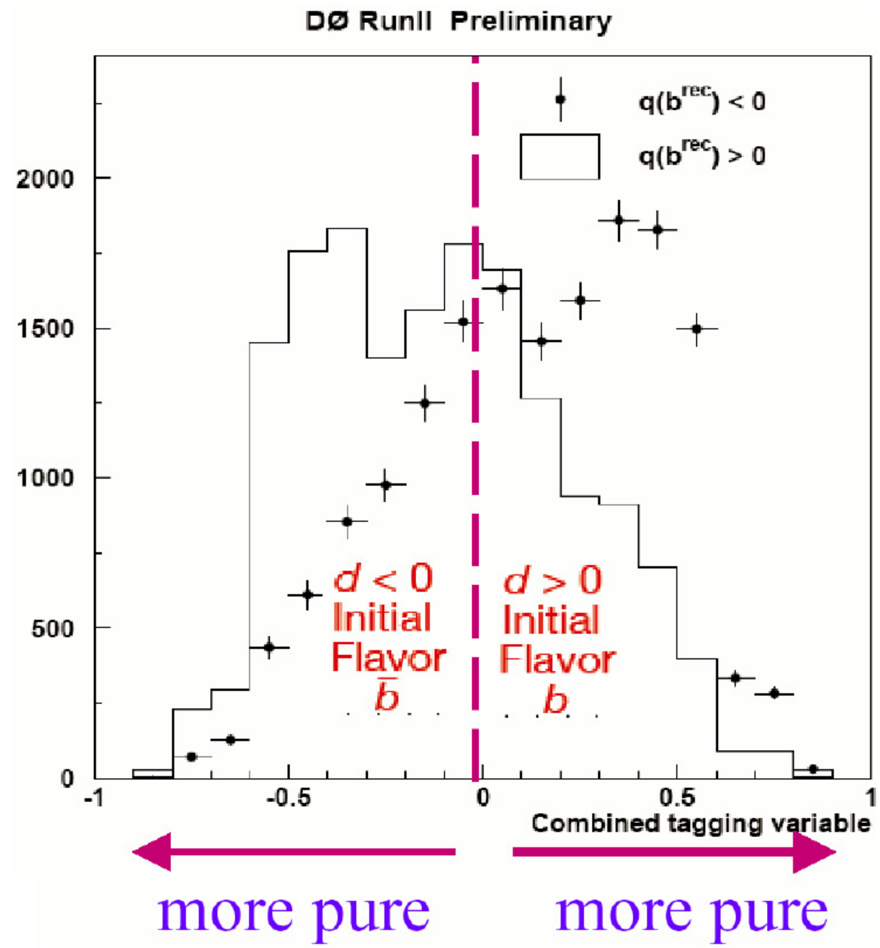
- Tagged = e, μ, or SV found away ($\cos\Delta\phi < 0.8$) from B_s

- Lepton (jet), SV, and event charges sensitive to flavor

- Combine variables, classify as b or $\overline{b}$ using likelihood ratio test

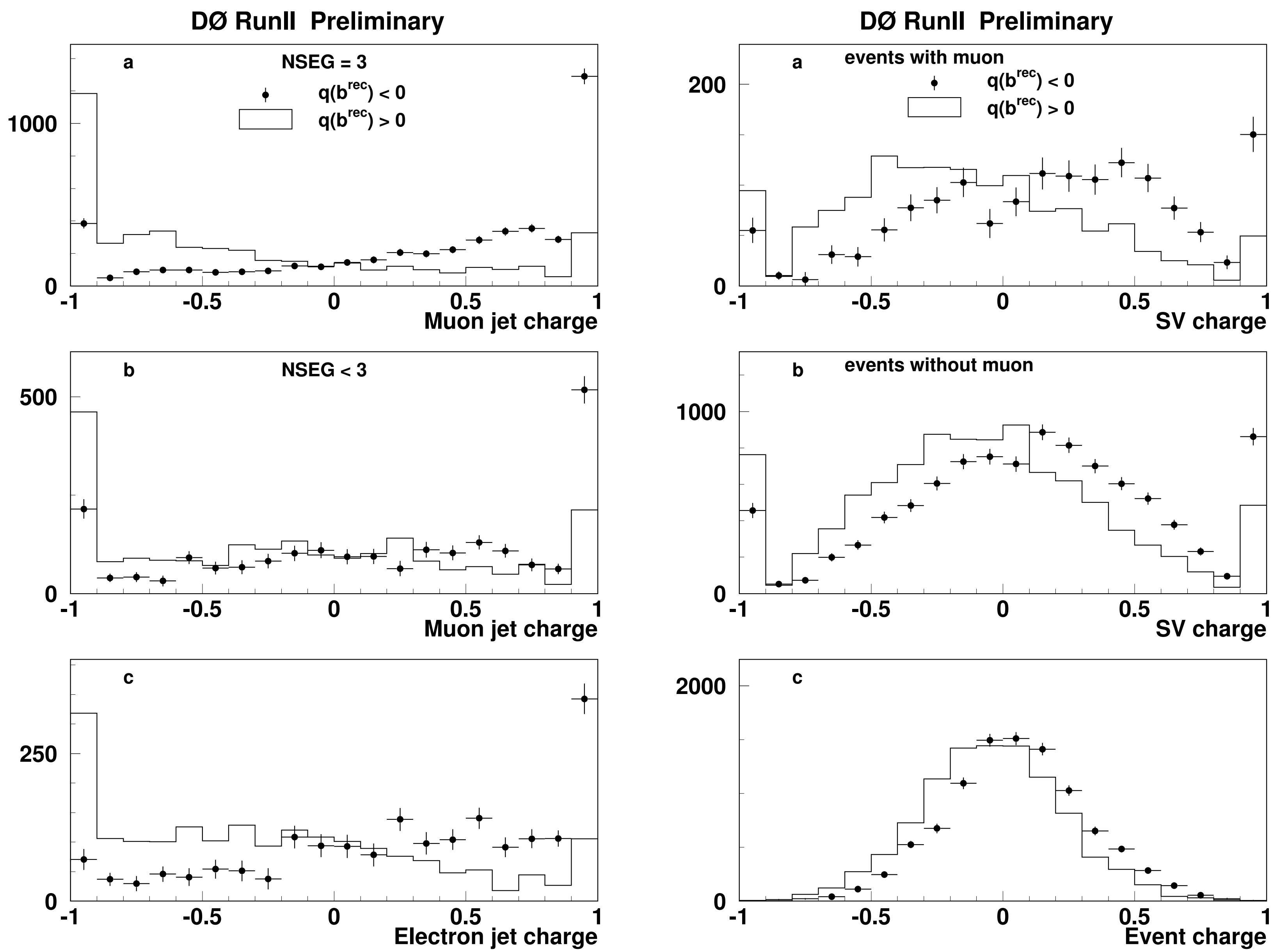
  $z = \frac{\text{likelihood}(\overline{b})}{\text{likelihood}(b)}$

  $d_{\text{tag}} = (1 - z)/(1 + z)$



Data, mainly $B^+ \to \mu^+ \nu \overline{D}^0$

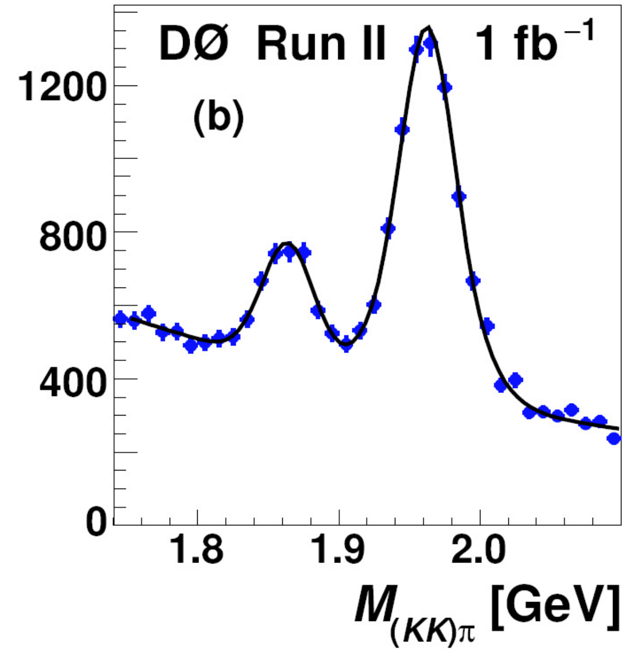
Charge Vari-ables



Momentur weighted averages.

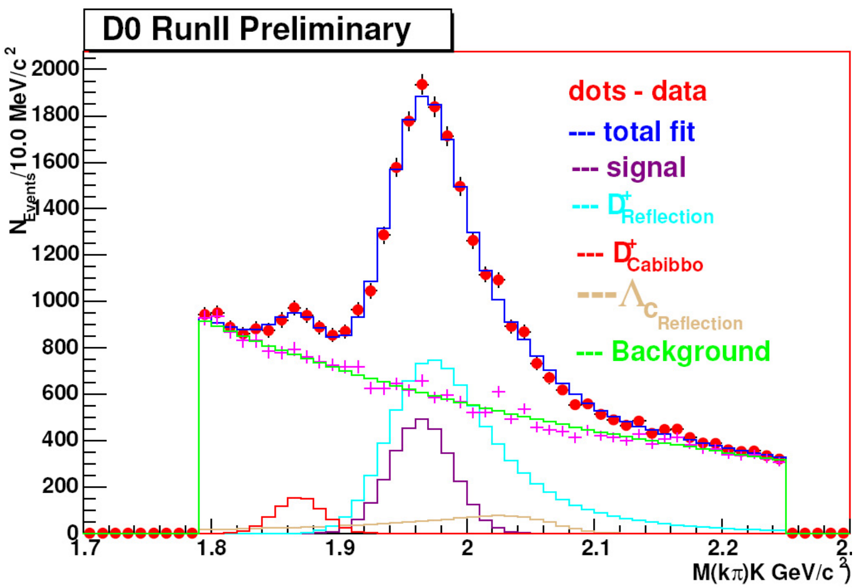
Measured in B^+ data.

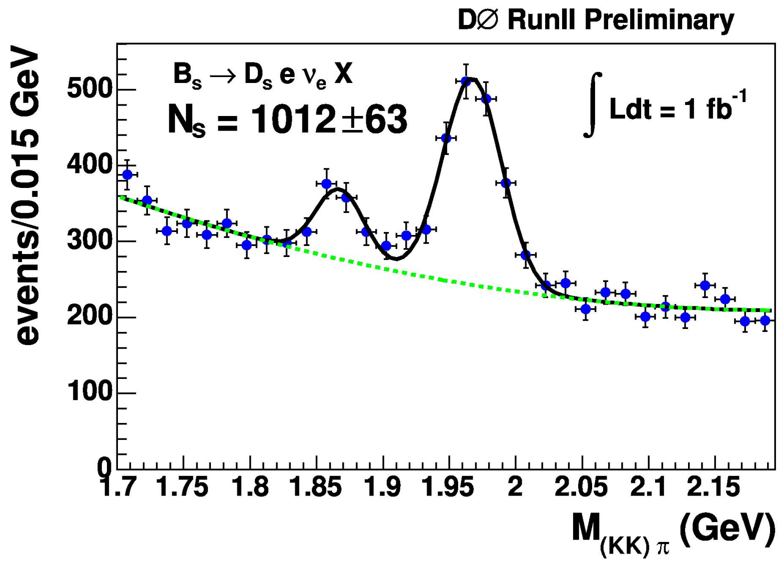
$B_s \rightarrow l^+ D_s^- X$
after-tag yields



$\mu^+\phi\pi^-$	$5,601 \pm 102$
$e^+\phi\pi^-$	$1,012 \pm 63$
$\mu^+K^{*0}K^-$	$2,997 \pm 146$

20% efficiency





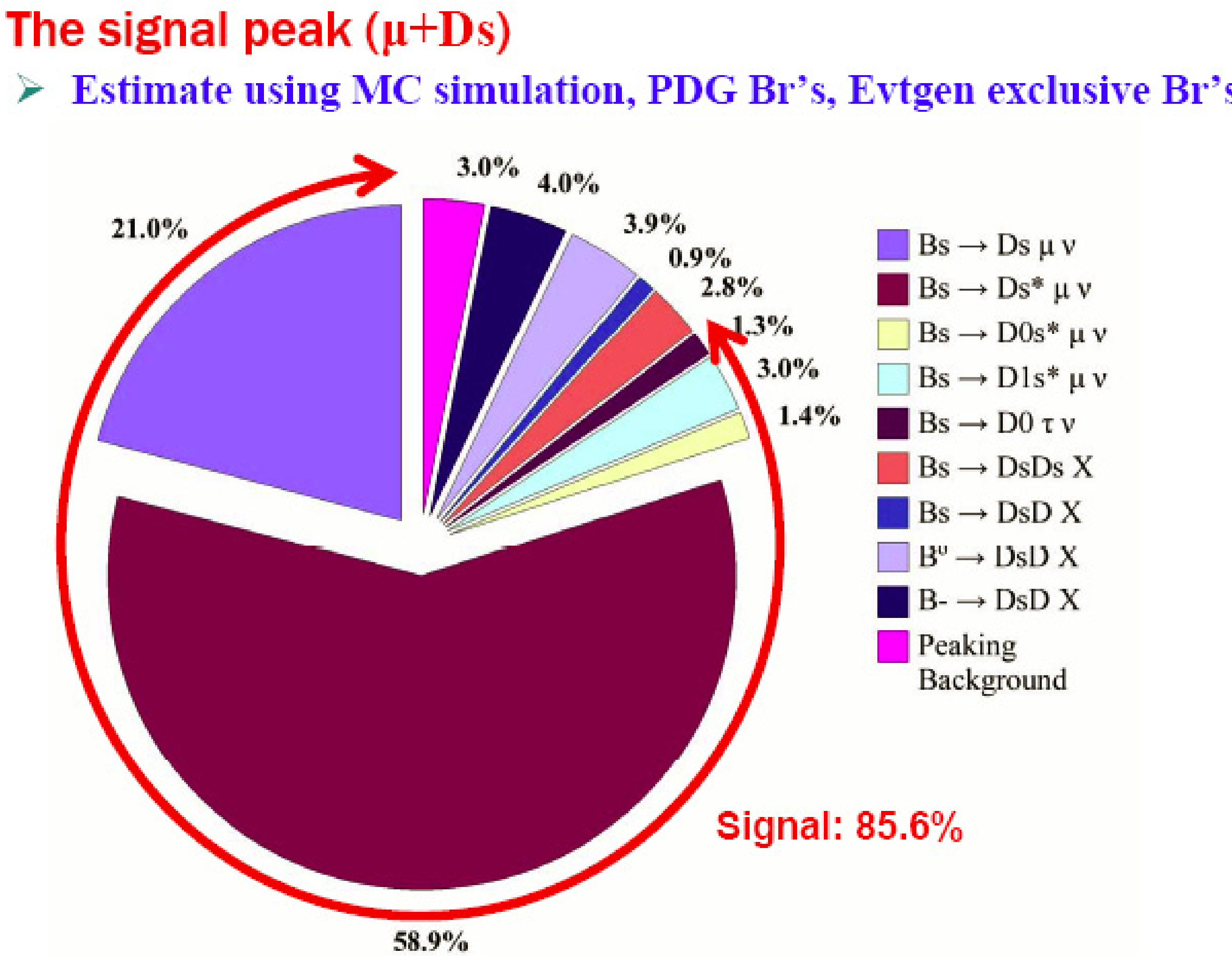
Discerning Δm_s

Unbinned likelihood function $\mathcal{L}(\text{data}|\Delta m_s)$

- ▷ Data: for each tagged event
  - VPDL
  - $\text{sign}(d_{\text{tag}})$
  - $|d_{\text{tag}}|$
  - Reconstructed D_s^- mass
  - Selection likelihood ratio
  - VPDL uncertainty
- ▷ Include all relevant signal and background sources

Sources

- $l^+D_s^-$
- l^+D^-
- Reflections
- Combinatorial backgrounds
  - long lived
    - insensitive to tag
    - sensitive to tag
      - non-oscillating
      - oscillating at Δm_d
  - prompt
  - fake vertices



VPDL term for signal sources

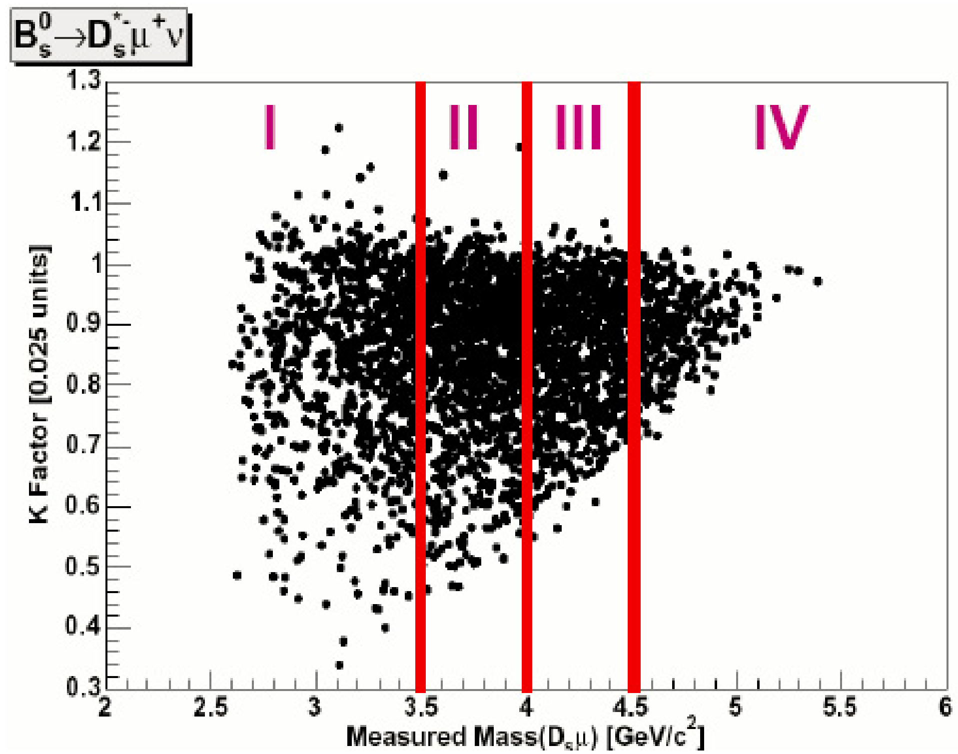
$$p^{\mathrm{nos/osc}}(x, K, d_{\mathrm{tag}}) = \frac{K}{c\tau_{B_s^0}} \exp(-\frac{Kx}{c\tau_{B_s^0}})[1 \pm \mathcal{D}(|d_{\mathrm{tag}}|) \cos(\Delta m_s \cdot Kx/c)]/2$$

$x = \mathrm{VPDL}$

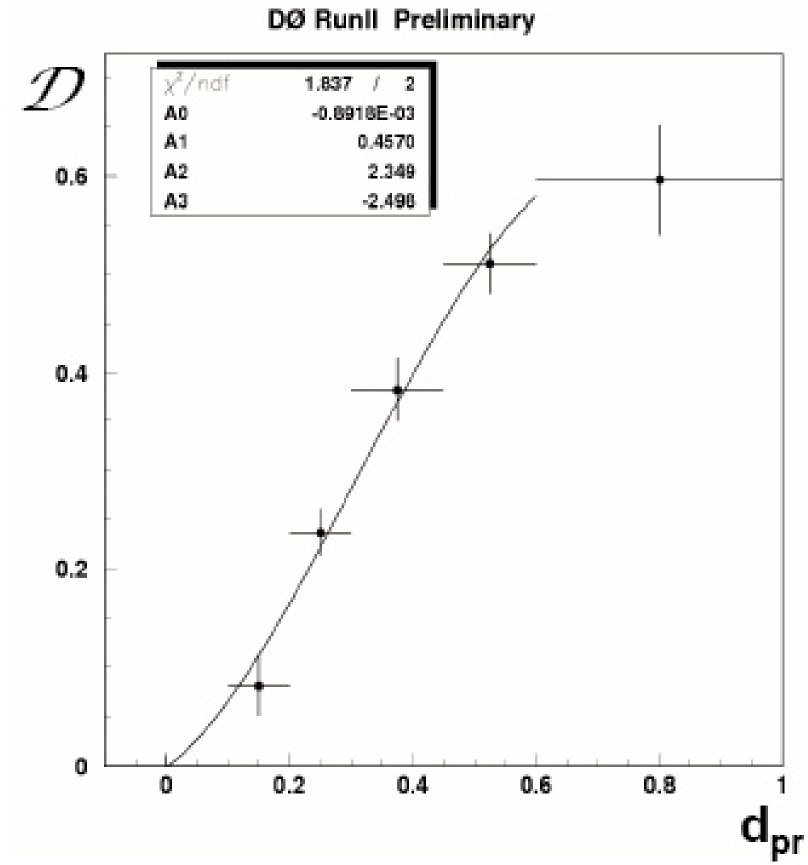
$K = p_T(l^+ D_s^-)/p_T(B)$, fold over appropriate K distribution

$\mathcal{D} = 2 \times \mathrm{prob(tag\ is\ correct)} - 1$

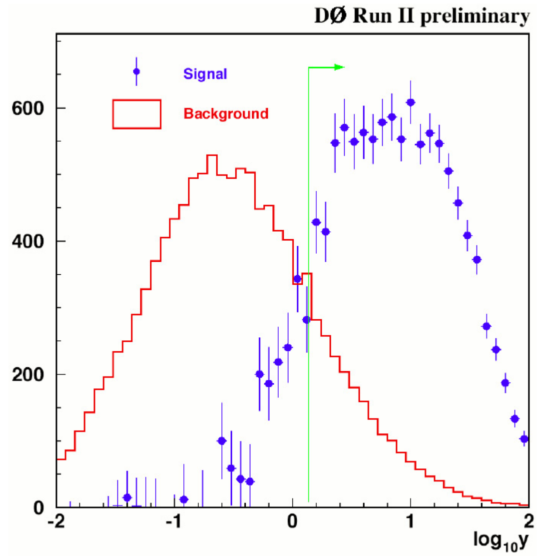
K distributions binned in $M(l^+D_s^-)$



$\mathcal{D}$ vs $d_{\rm tag}$ measured in B_d^0 data

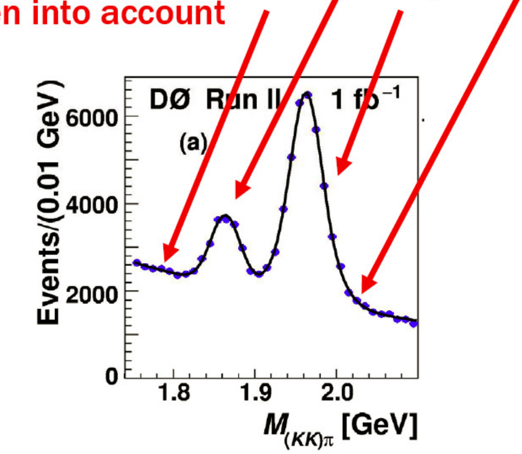


$\log_{10}$(Selection likelihood ratio)



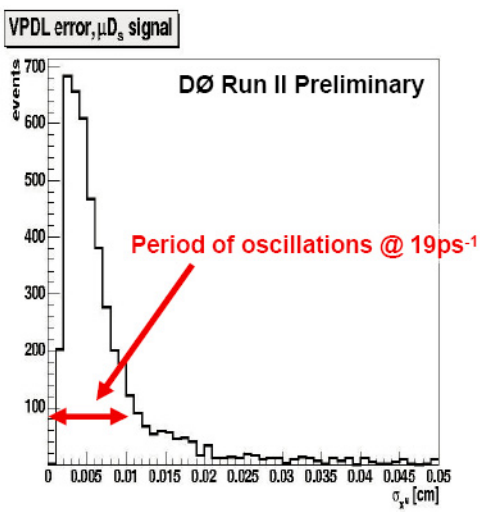
$(K^+K^-)\pi^+$ Mass

Contributions of background, D^+, D_s and D^+ reflections are taken into account

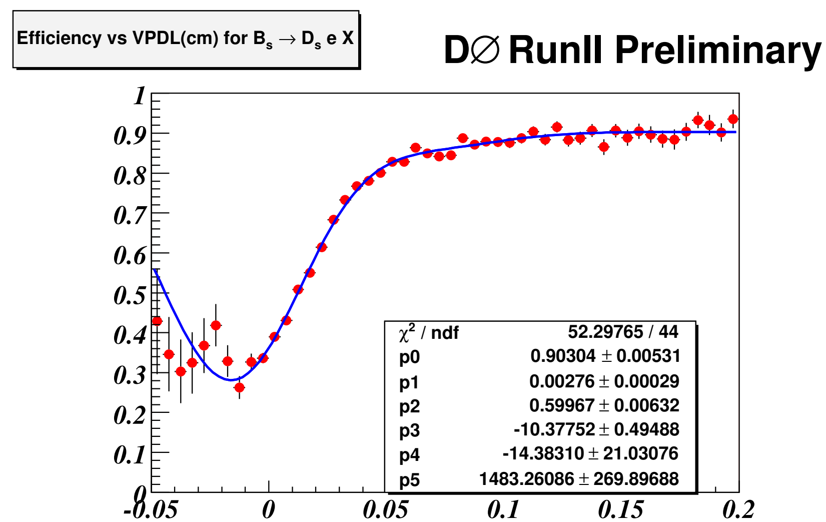


Fit in the entire mass region from 1.72 to 2.22 GeV

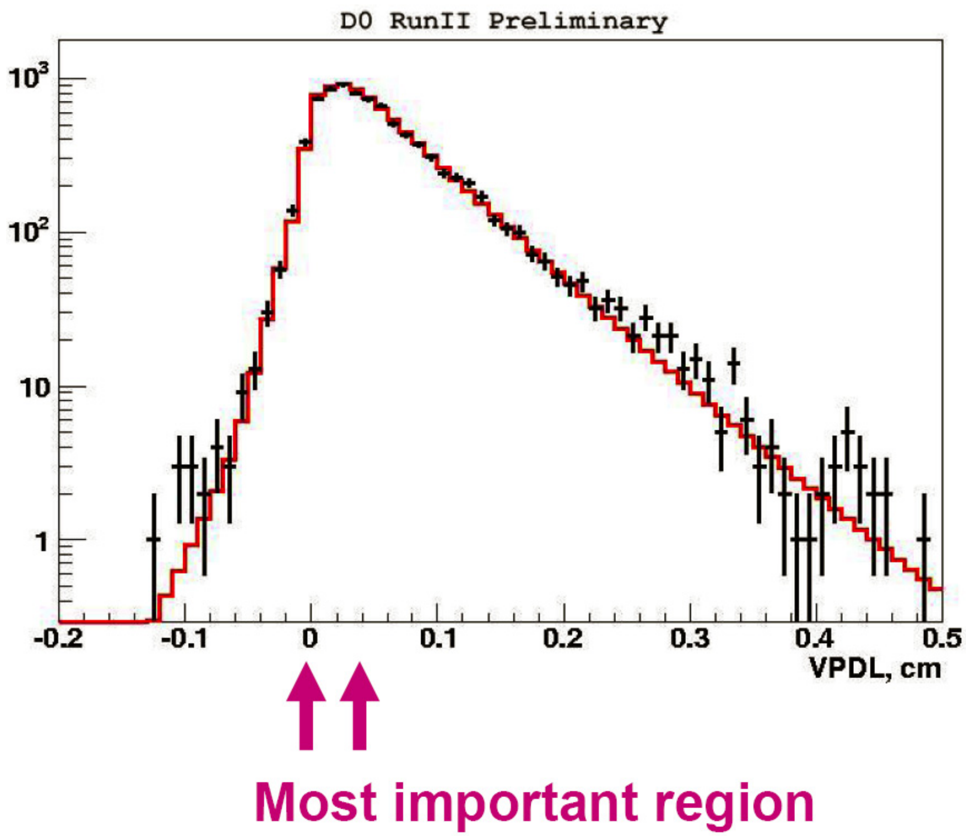
VPDL Uncertainty



Efficiency vs VPDL



B_s Lifetime Fit



Amplitude scan procedure

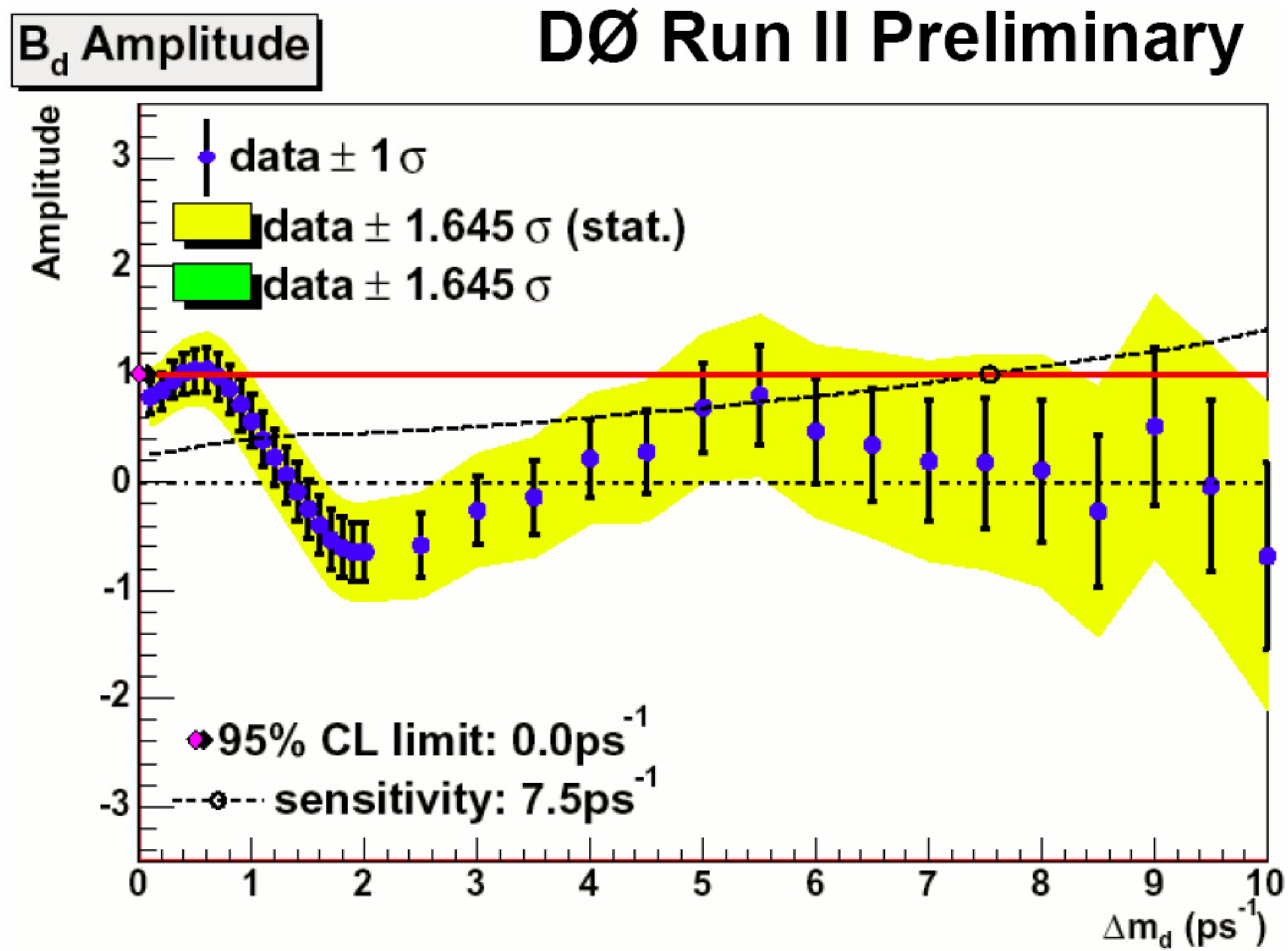
Insert artificial parameter A

$$p^{\mathrm{nos/osc}}(x, K, d_{\mathrm{tag}}) \propto [1 \pm \mathcal{D}(|d_{\mathrm{tag}}|) \cdot A \cdot \cos(\Delta m \cdot Kx/c)]$$

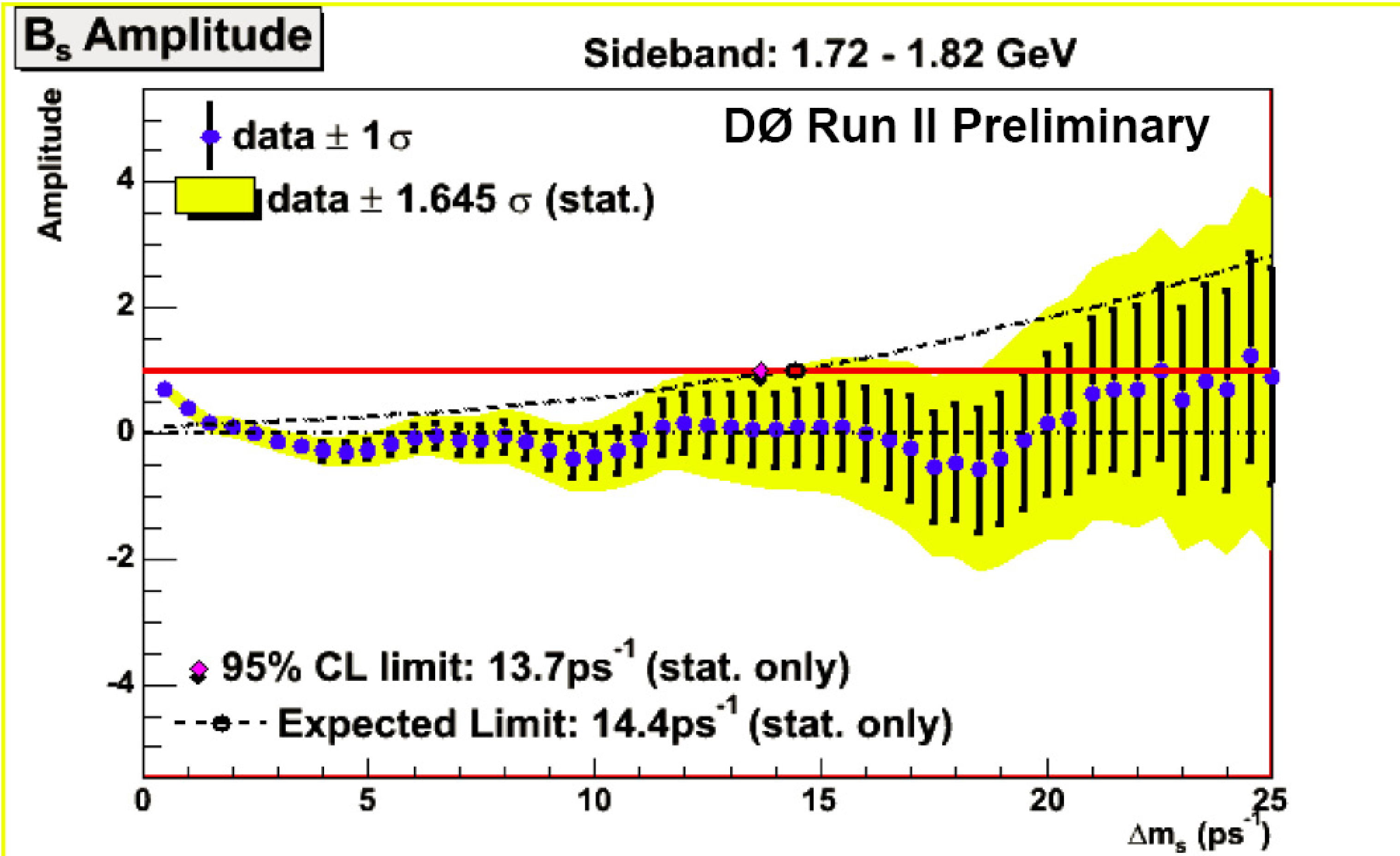
Fix Δm and fit for A

- $A = 1$ for true Δm
- $A = 0$ otherwise

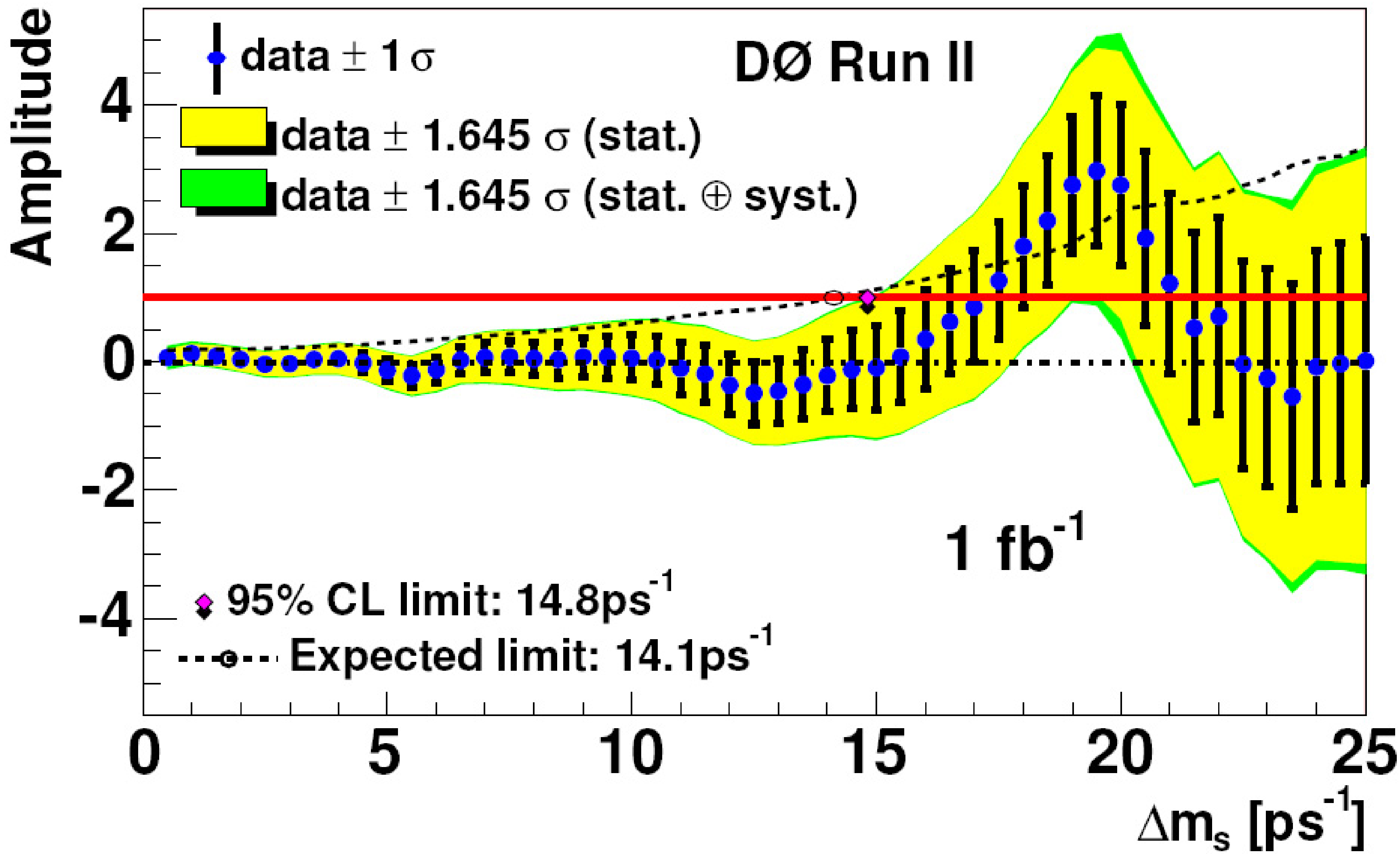
Amplitude scan of Δm_d in $B_d^0 \to \mu^+ D^- X$



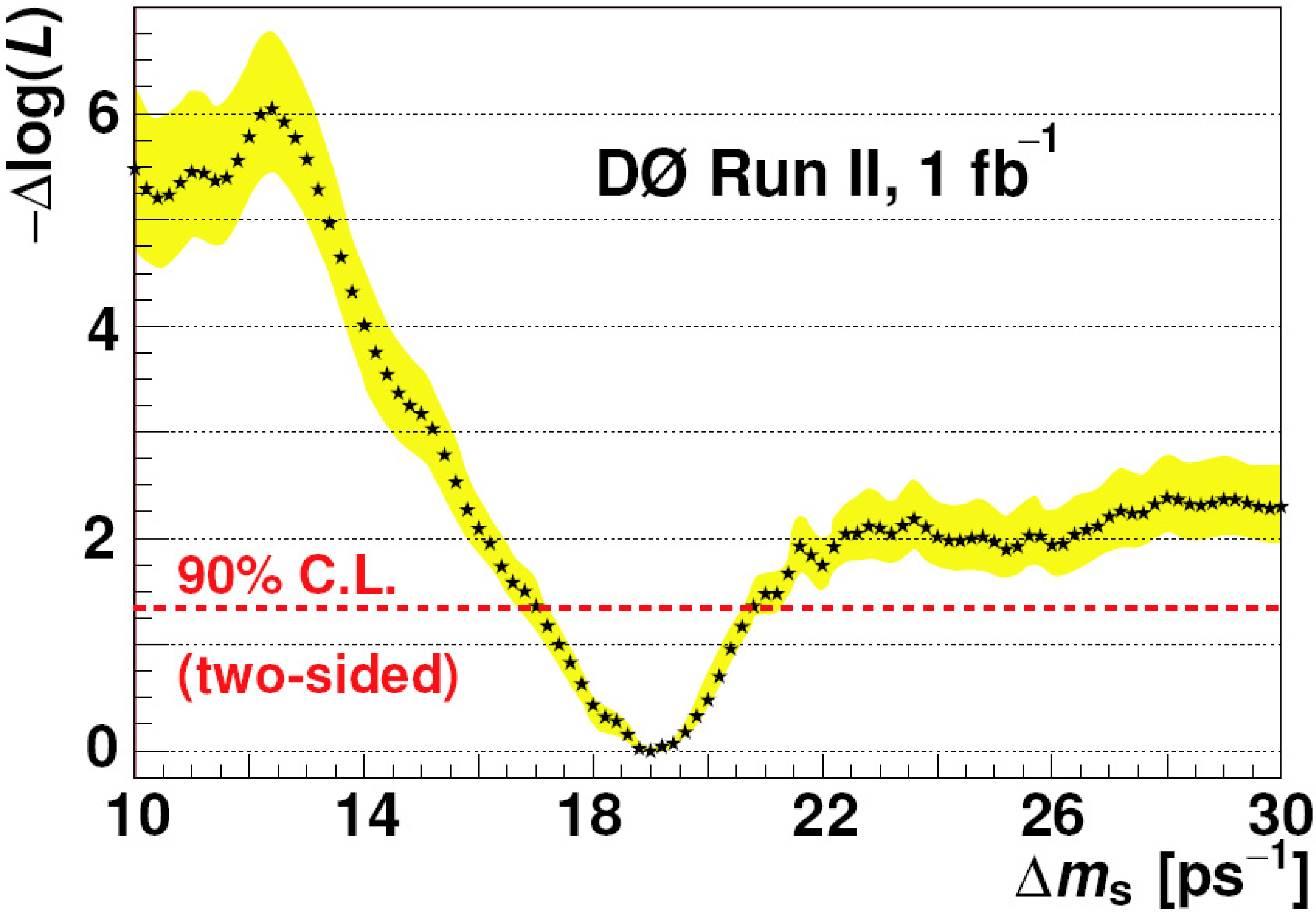
Amplitude scan of Δm_s in D_s^- sideband



Amplitude scan: $B_s \to \mu^+ \phi \pi^- X$



Likelihood scan: $B_s \to \mu^+\phi\pi^- X$



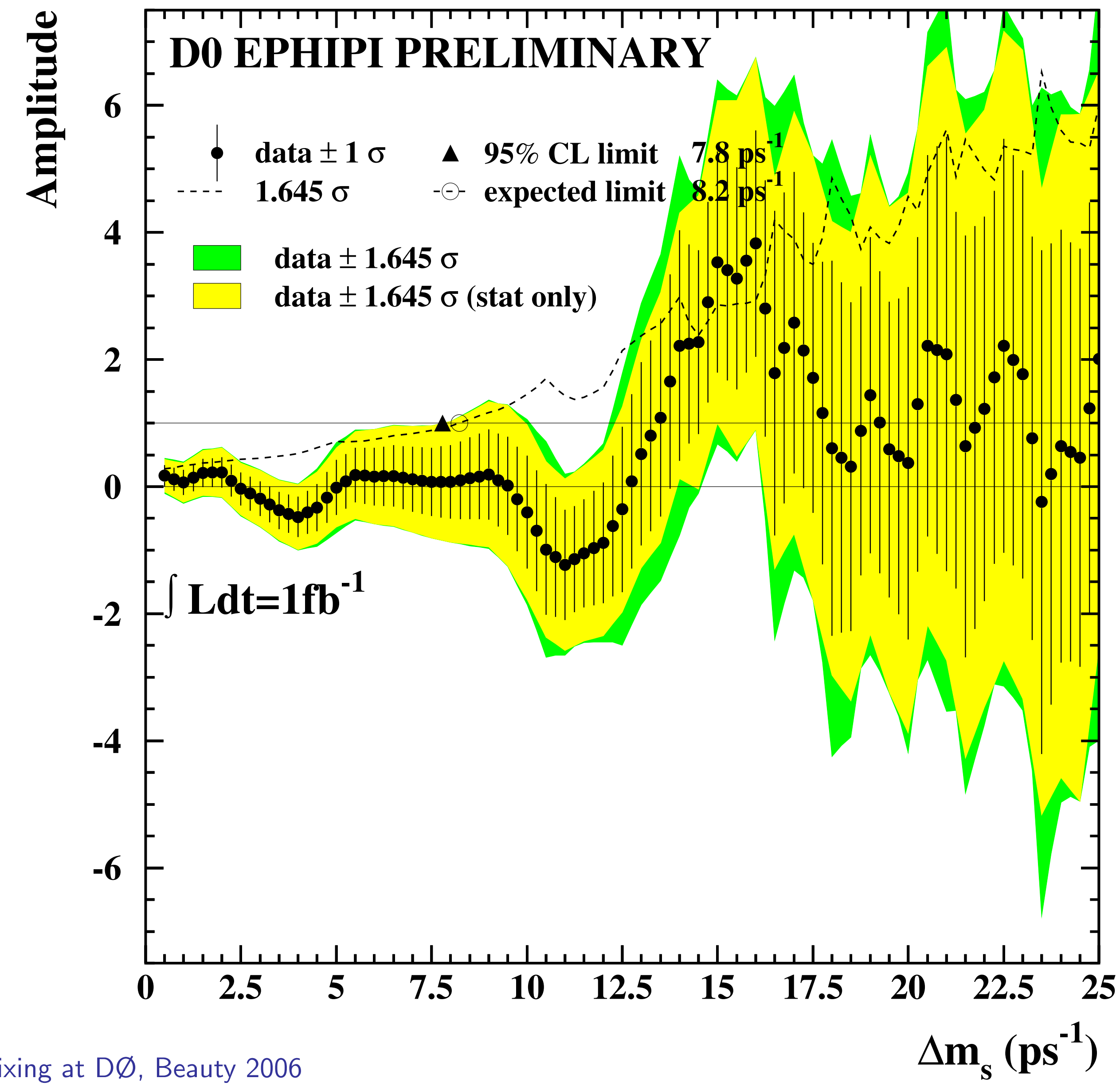
Statistical significance

How often is the $-\log\mathcal{L}$ minimum in the range $16 < \Delta m_s < 22$ ps^{-1} and at least 1.7 below $\log\mathcal{L}$ at $\Delta m_s = 25$ ps^{-1} if $\Delta m_s = \text{inf}$?

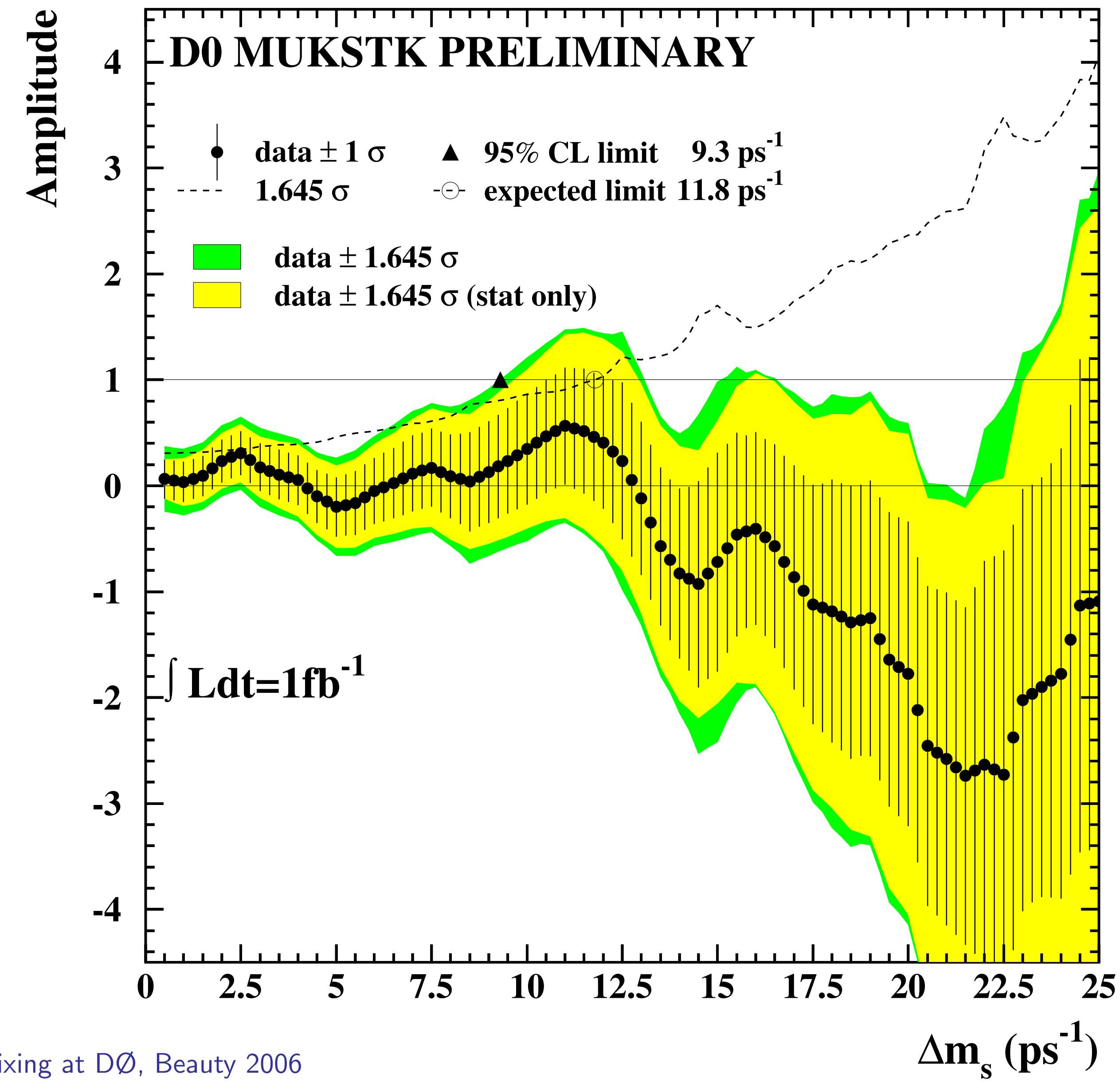
Ensemble tests with sign of flavor tag randomized:

$5.0 \pm 0.3\%$

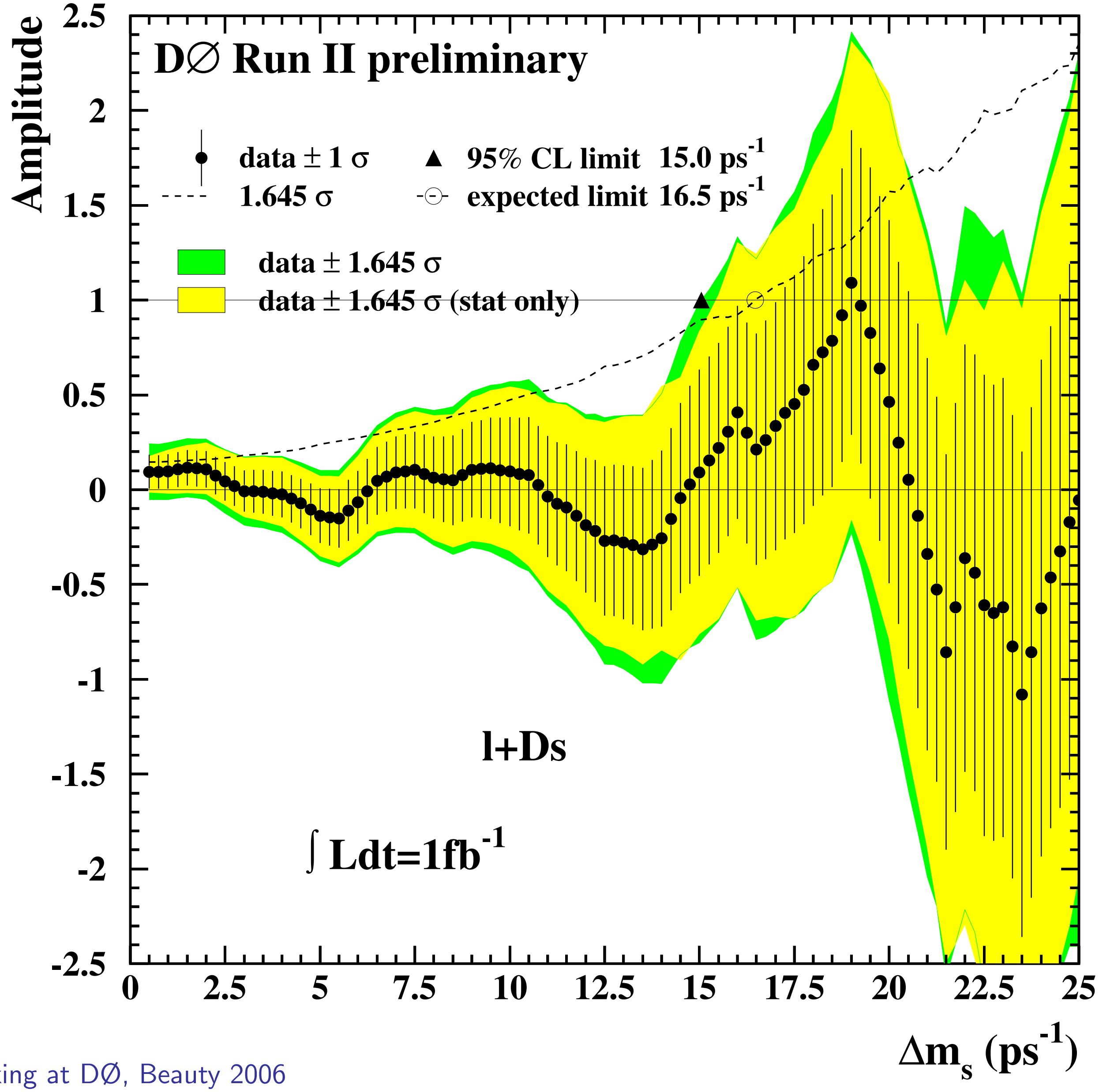
Amplitude scan: $B_s \to e^+\phi\pi^-X$



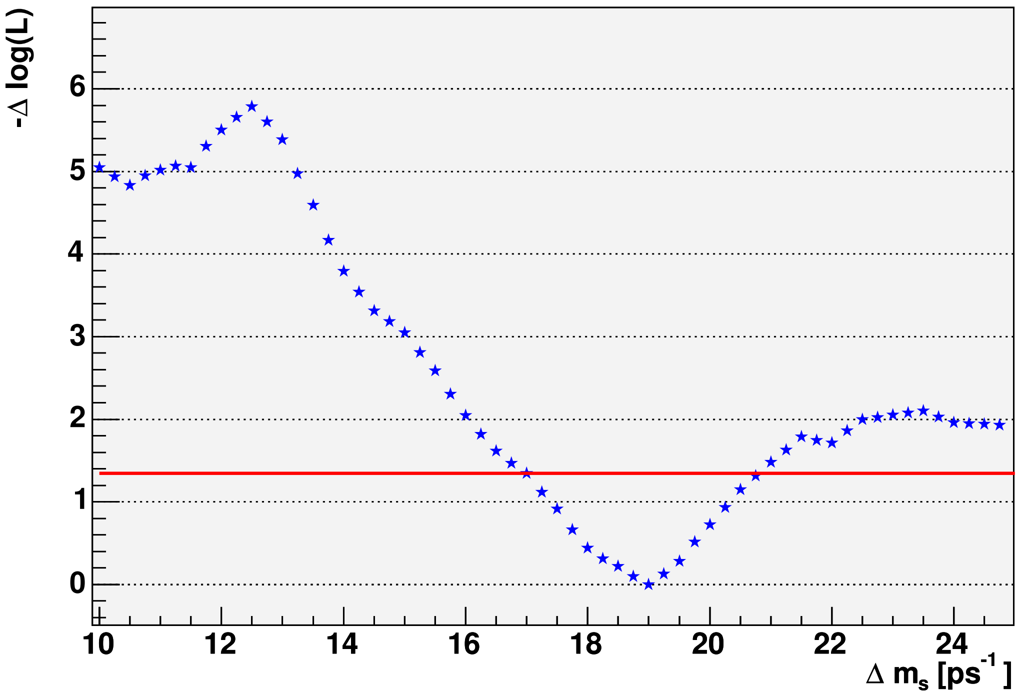
Amplitude scan: $\mu^+ K^{*0} K^- X$



Amplitude scan: combined channels

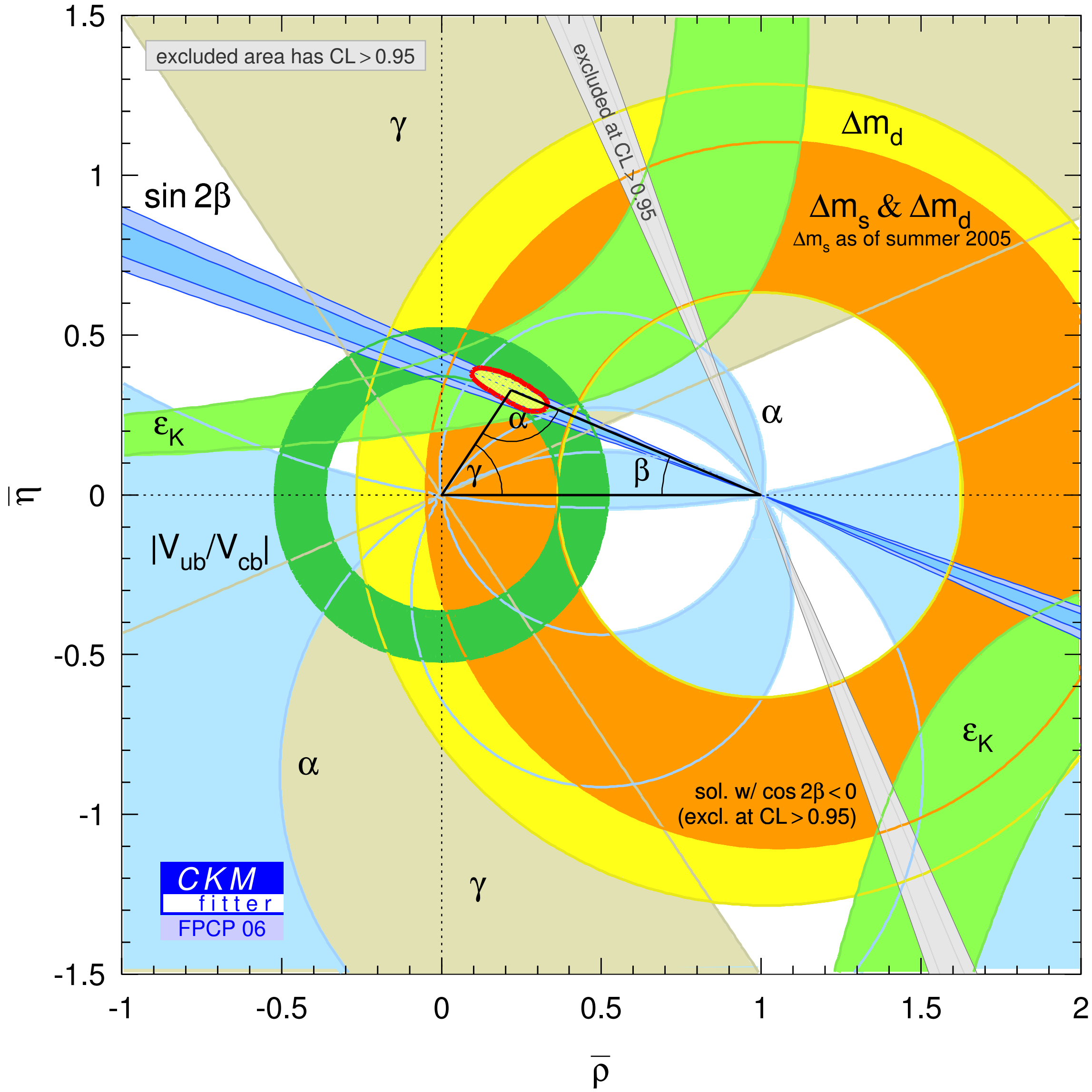


Combined Likelihood Curve

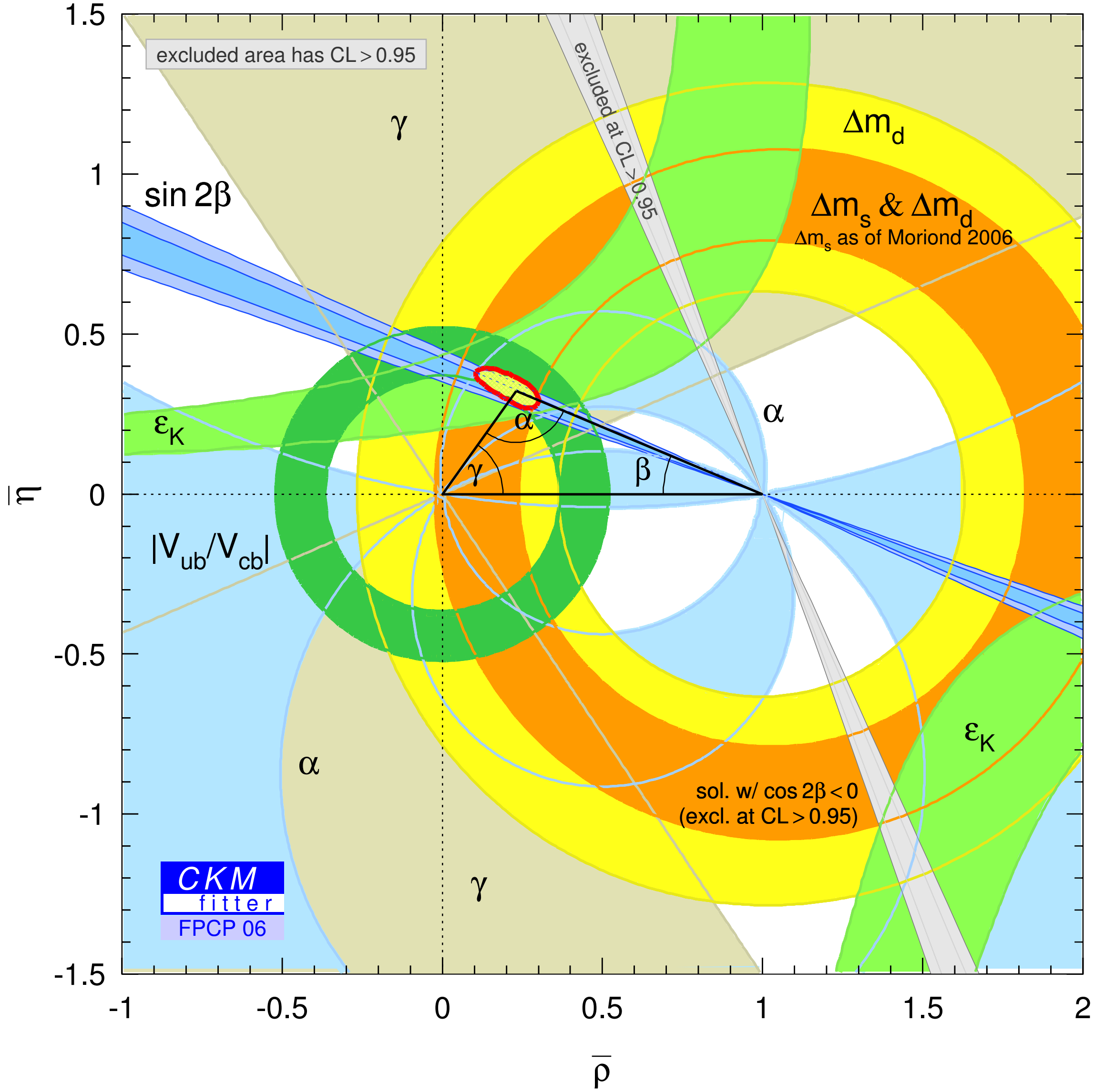


- Estimated from combined amplitude scan
- Same 90% C.L. interval as $\mu^+\phi\pi^-$ alone
- Background fluctuation probability approximately 8%

CKM Triangle Before $\mu^+\phi\pi^-$ Result



CKM Triangle After $\mu^+\phi\pi^-$ Result



Conclusions

- DØ has produced results on B_s–$\overline{B}_s$ oscillations using three decay modes
  - $B_s^0 \to \mu^+ D_s^- X,\ D_s^- \to \phi\pi^-$
  - $B_s^0 \to \mu^+ D_s^- X,\ D_s^- \to K^{*0} K^-$
  - $B_s^0 \to e^+ D_s^- X,\ D_s^- \to \phi\pi^-$
- The combined amplitude scan gives a limit $\Delta m_s > 15.0$ ps^{-1} at 95% C.L.
- The combined likelihood curve has a preferred value of $\Delta m_s = 19$ ps^{-1}, with a 90% C.L. interval of $17 < \Delta m_s < 21$ ps^{-1}.
- The probability of a background fluctuation is about 8%.
- Future results will feature additional decay modes and data with a new layer of silicon at the beampipe.