B_s Oscillation, V_{td} & V_{ts}, and Rare decays

Iain Bertram
Department of Physics
Lancaster University

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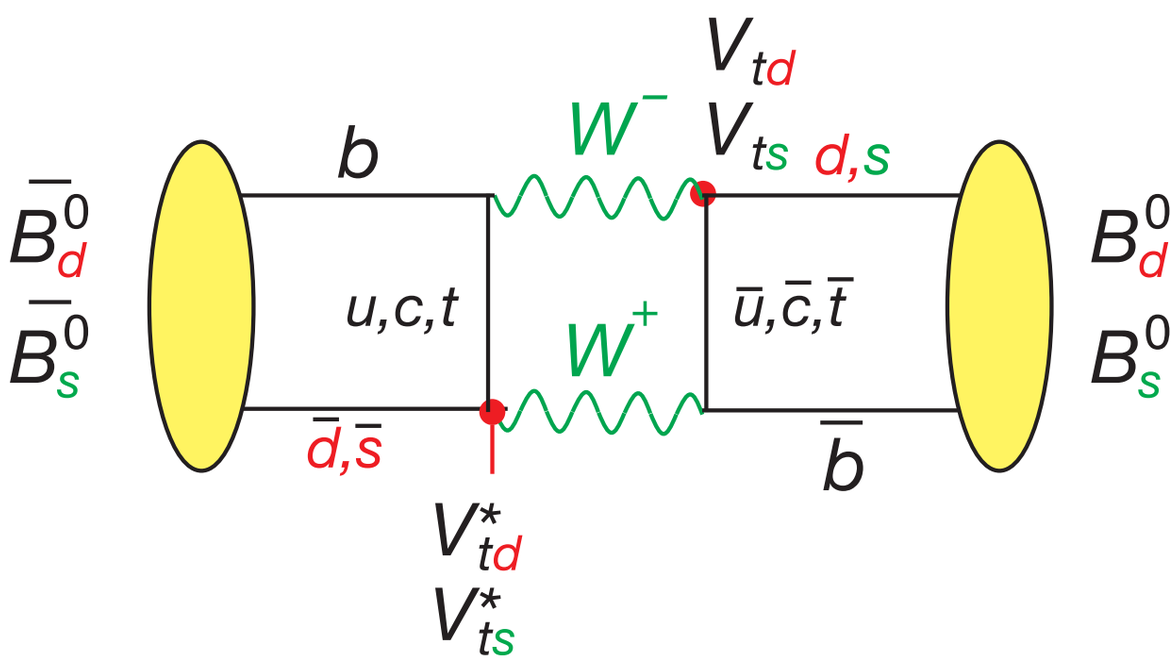
B Mixing and Oscillations

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

CP Eigenstates: $|B^{\text{even}}\rangle = |B^0\rangle + |\bar{B}^0\rangle \quad |B^{\text{odd}}\rangle = |B^0\rangle - |\bar{B}^0\rangle$

Mass Eigenstates: $|B^H\rangle = p|B^0\rangle + q|\bar{B}^0\rangle \quad |B^L\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$

- Mass Difference: $\Delta m = M_H - M_L \sim 2|M_{12}|$
  Directly probes V_{td} and V_{ts} in oscillations of B_d & B_s



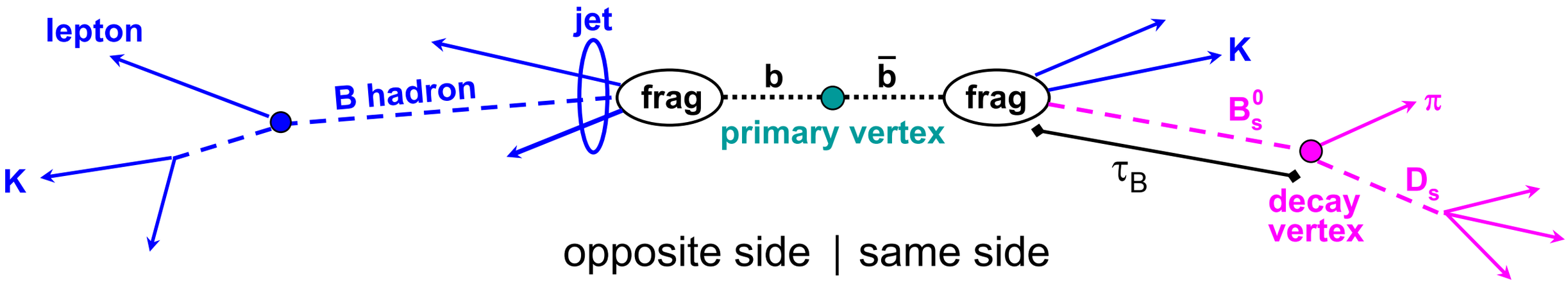
slow oscillation

fast oscillation

$$\Delta m_d \propto |V_{tb}^* V_{td}|^2$$
$$\Delta m_s \propto |V_{tb}^* V_{ts}|^2$$

Analysis Details

See Talk by H. Evans for details of measurement



opposite side | same side

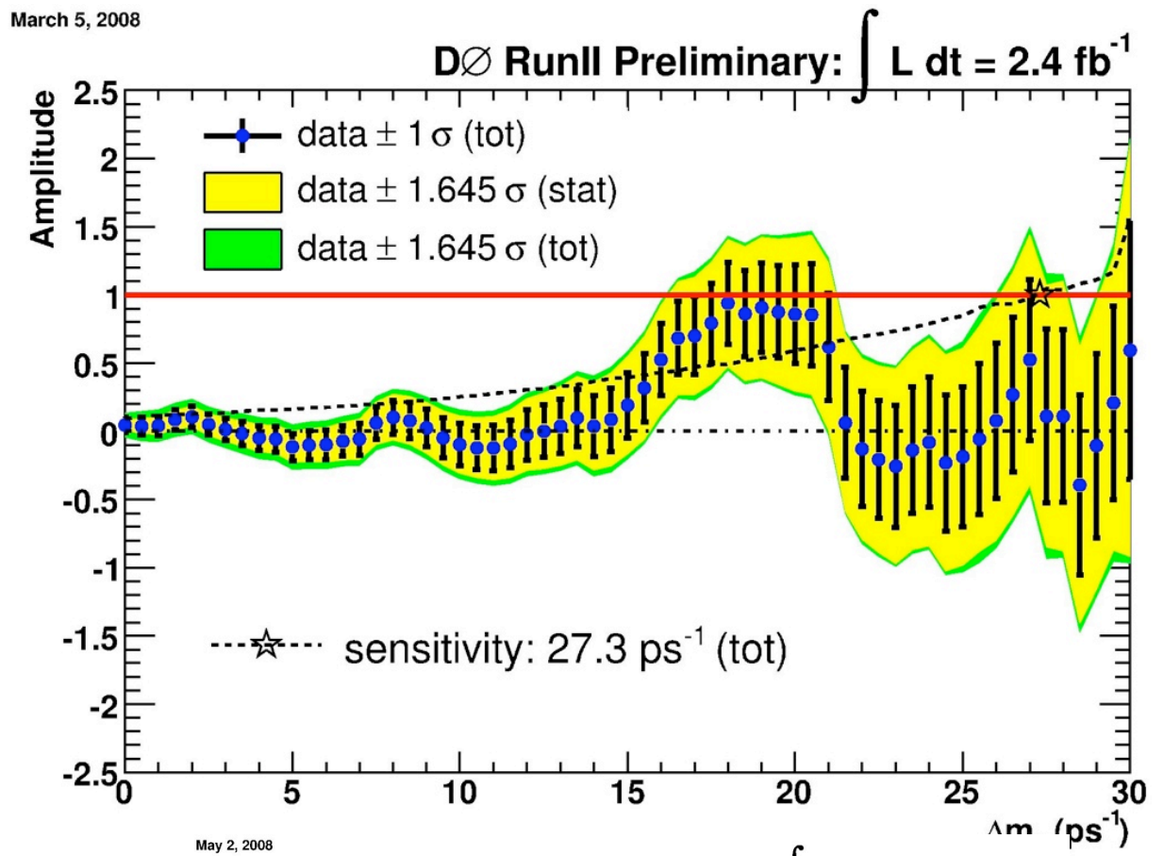
1. Measurement of production flavour
   - OS kaon flavour
   - SS kaon flavour
   - lepton flavour $b \to Xl^-$, but $b \to c \to xl^+$
   - Jet Charge multivariate

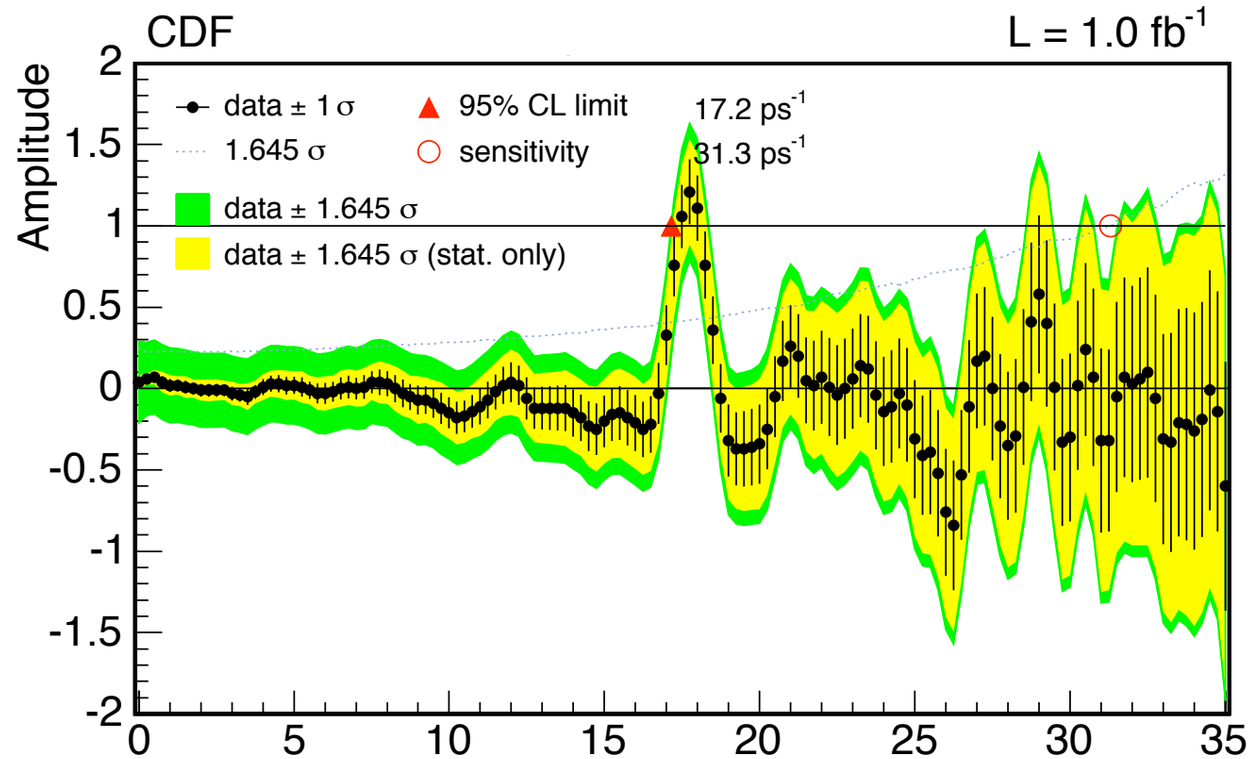
2. Measurement of decay flavour
   - lepton or flavour specific final state

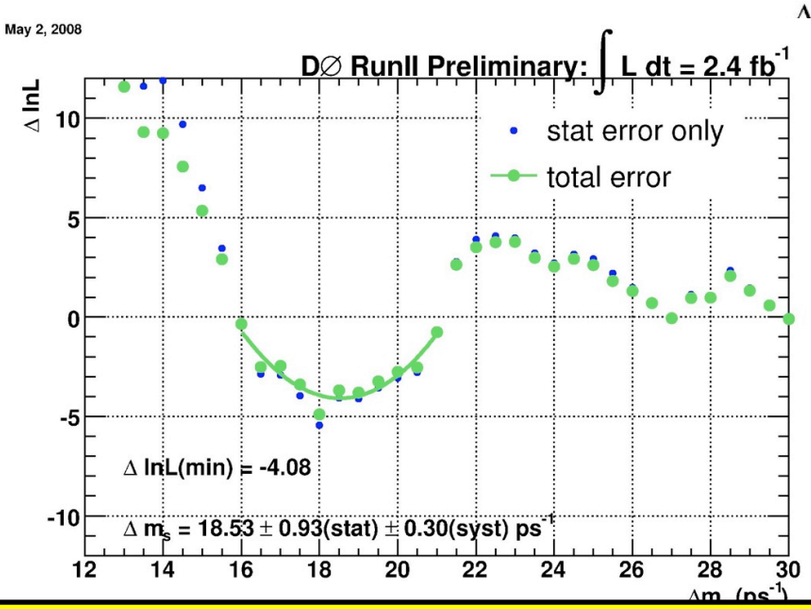
3. Measurement of Proper Time
   - depends on resolution of tracking system

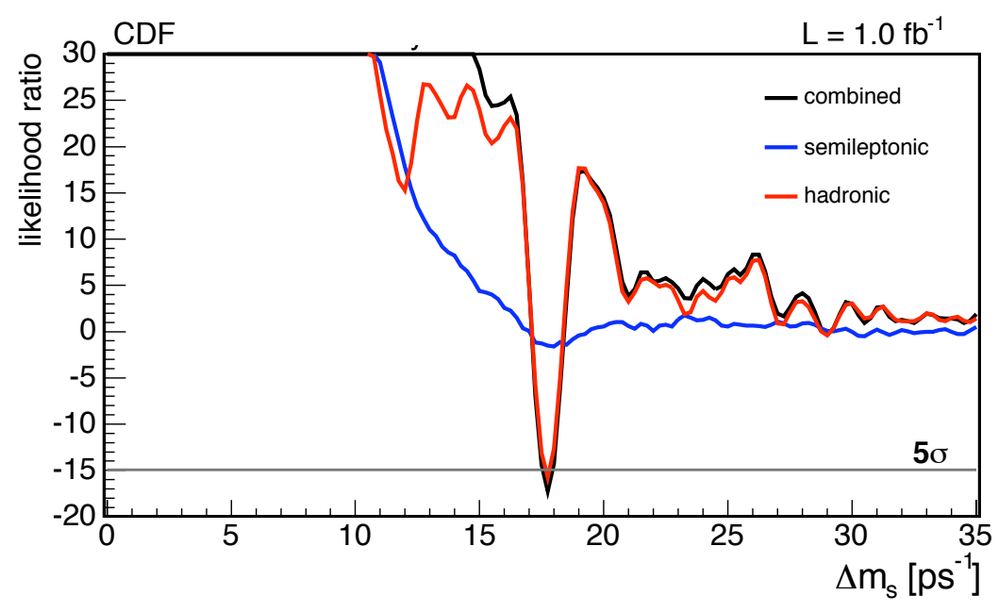
Δm_s Measurements

See Talk by H. Evans for details of measurement









DØ: 2.9 σ significance
$\Delta ms = 18.53 \pm 0.93(stat) \pm 0.30(syst)\ ps^{-1}$

CDF: >5σ significance
$\Delta ms = 17.77 \pm 0.10(stat) \pm 0.07(sys)$

Vts & Vtd

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

D0: 0.2018 ±0.0053(exp) ± 0.0010(Δmd) +0.0078-0.0058(ξ)
CDF: 0.2060 ±0.0007(exp) ± 0.0010(Δmd) +0.0080-0.0060(ξ)

Ave: 0.2059 ±0.0007(exp) ± 0.0010(Δmd) +0.0080-0.0060(ξ)

- Uncertainty driven by theoretical calculation of ξ.
- Full Uncertainties (added in naive quadrature)
  - D0 - 4.3% CDF - 3.5%
  - Require theoretical improvements to progress here...

Future of Vts & Vtd

- Progress needs to be made on lattice calculations of ξ

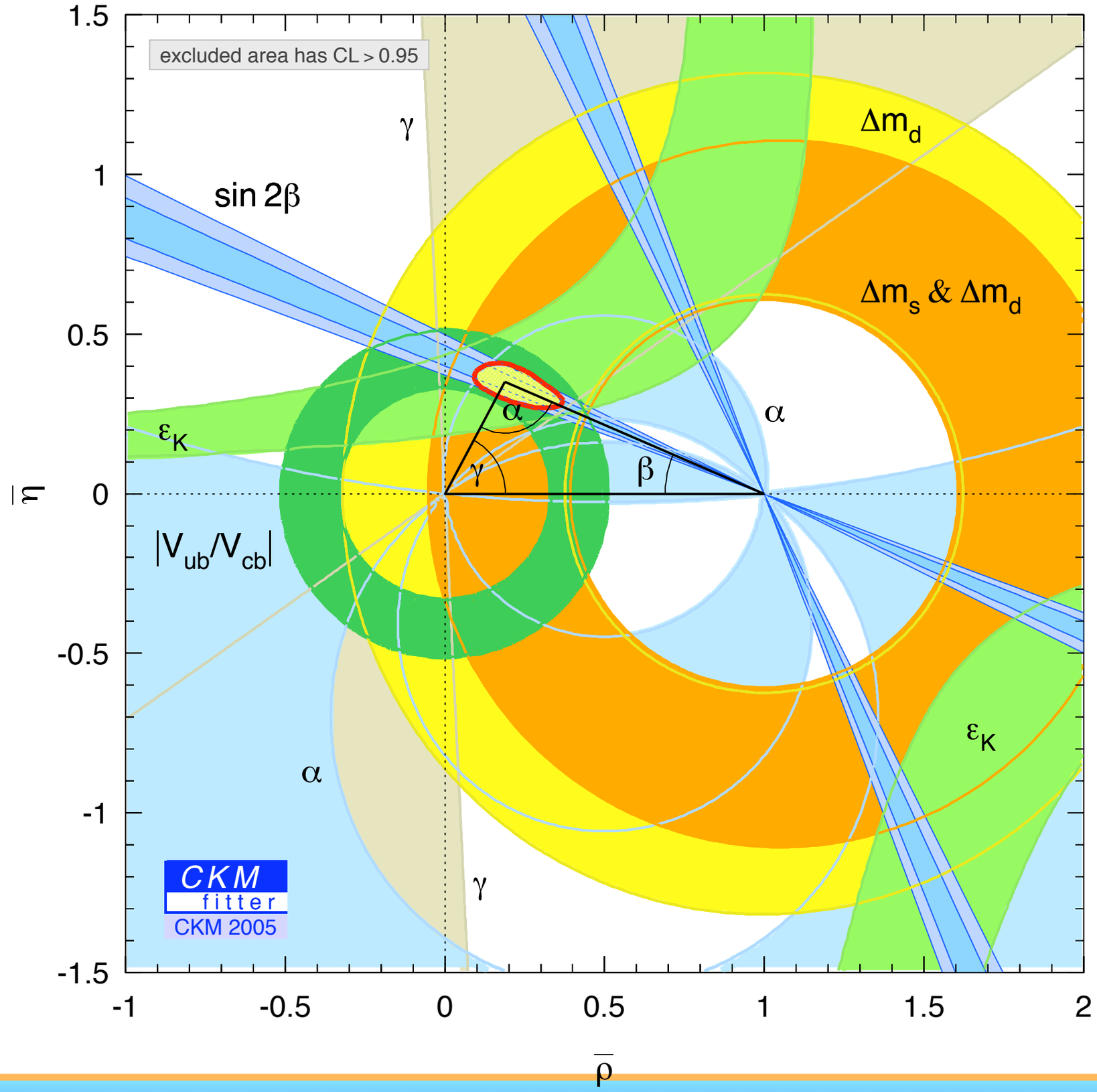
Swiped from:Elvira G´amiz
Lattice QCD Meets Experiment Workshop
Fermilab, 11 December 2007

$$\left|\frac{V_{td}}{V_{ts}}\right| = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_{B_d}\sqrt{B_{B_d}}} \qquad \sqrt{\frac{\Delta M_d M_{B_s}}{\Delta M_s M_{B_d}}}$$

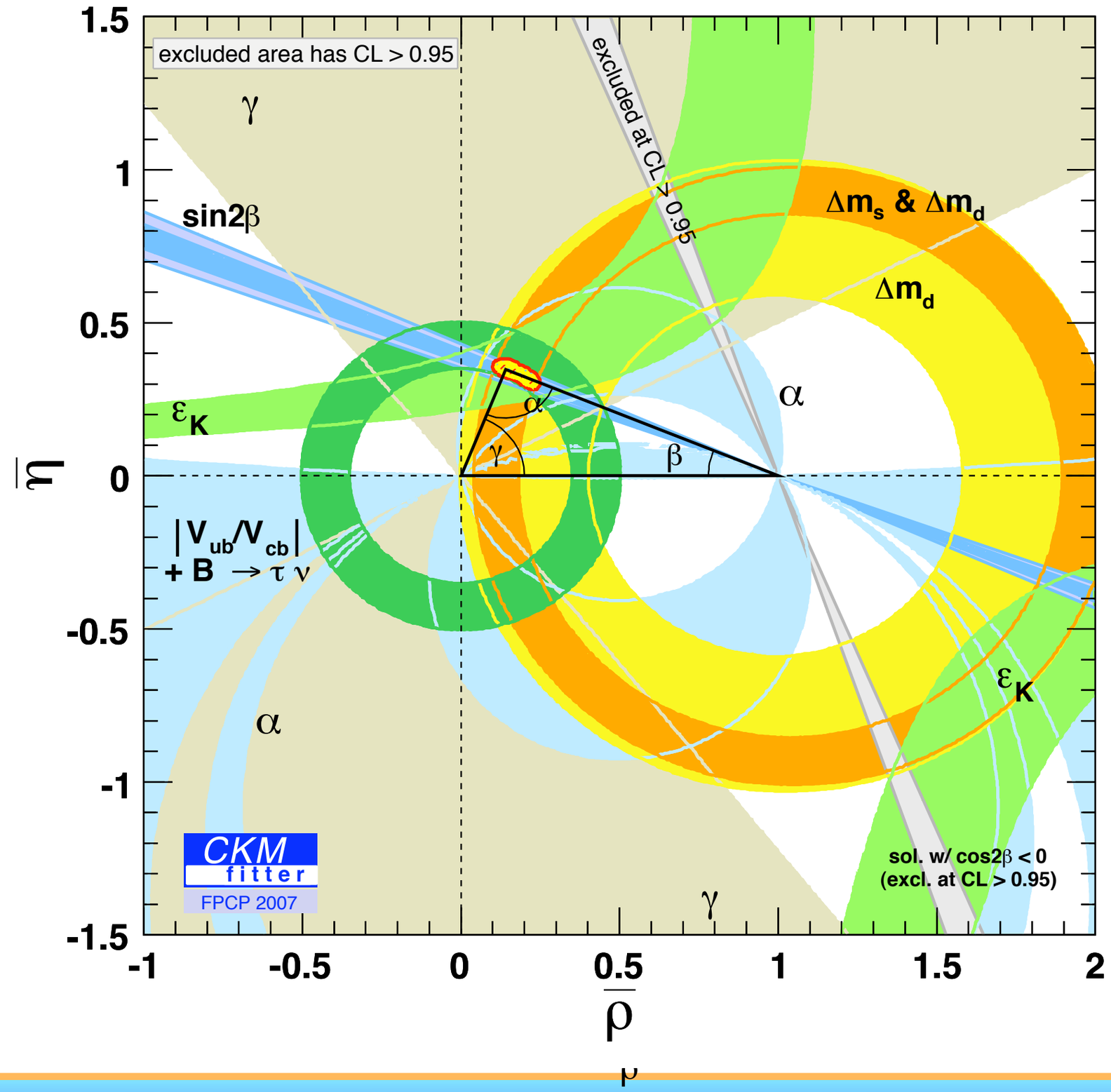
	$f_{B_q}\sqrt{B_{B_q}}$	ξ
statistics+fitting	$1-3\%$	$\sim 1-2\%$
inputs (a, m_b ...)	2.5%	$< 0.1\%$
Higher order matching	$\sim 3.5\%$ cancel to a large extent	
Heavy quark action	$1.5-2\%$	$< 0.2\%$
Light quark discret. + χPT fits	$2-4\%^*$	$< 2\%^*$
Total (estimate)	$5-7\%$	$2-3\%$

- Possibility of reducing errors by factor of 1.5 - 2 over next two years
  - Progress is difficult

Last Word on Oscillations



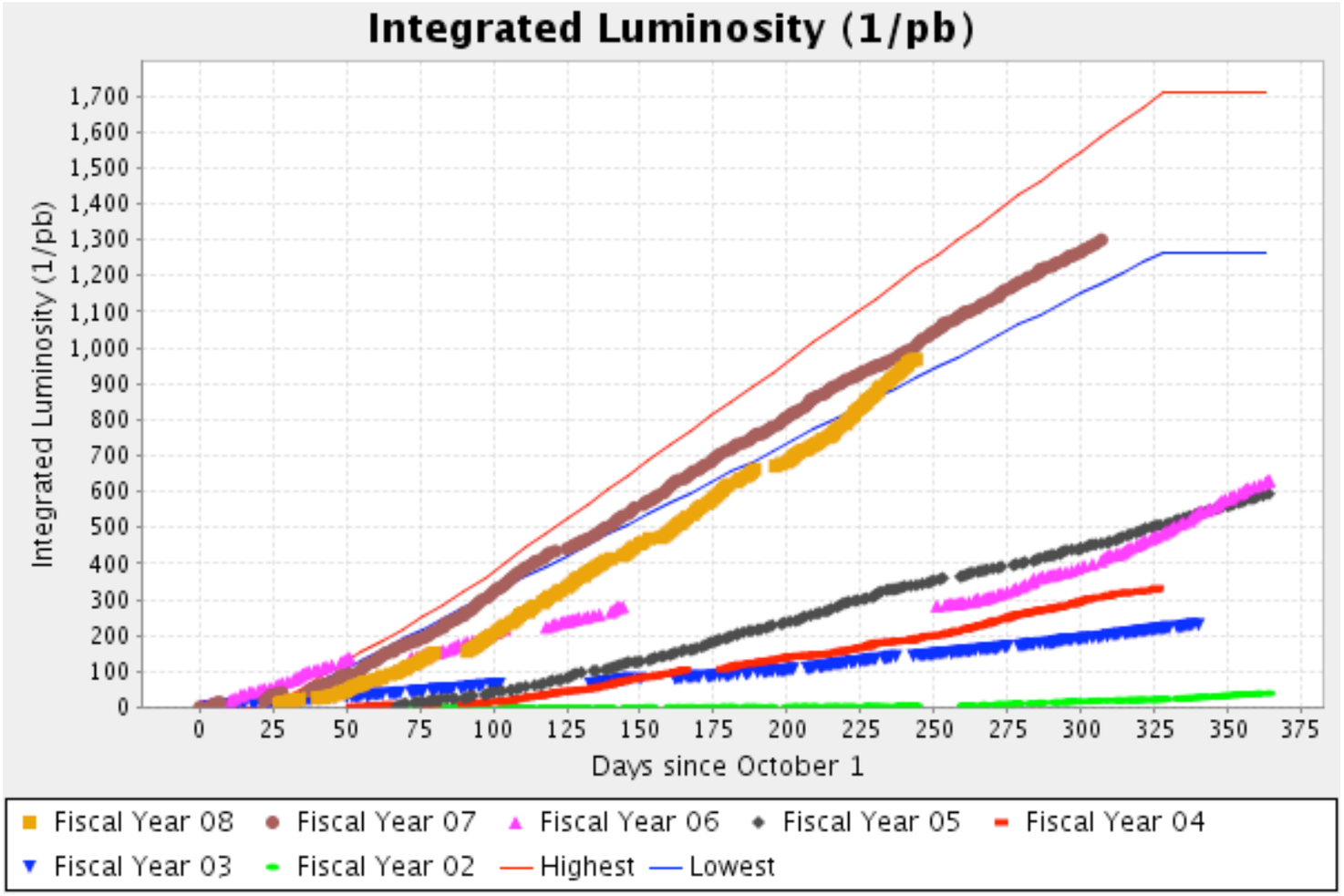
Last Word on Oscillations



Rare Decays

See Talk by M. Paulini for other B spectroscopy

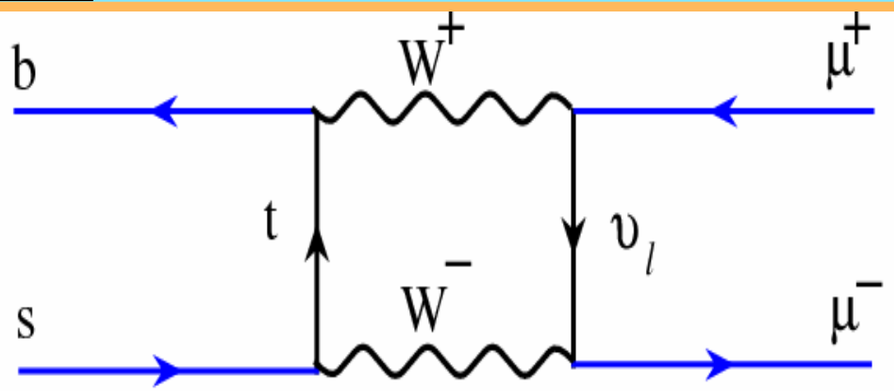
- Processes
  - $B_S \rightarrow \mu\mu$, $B_S \rightarrow \mu\mu X$ (CDF & D0)
  - D Decays (D0 & CDF)
- All Depend on Integrated Luminosity
- Analysis presented here uses up to 2 fb^{-1} of luminosity

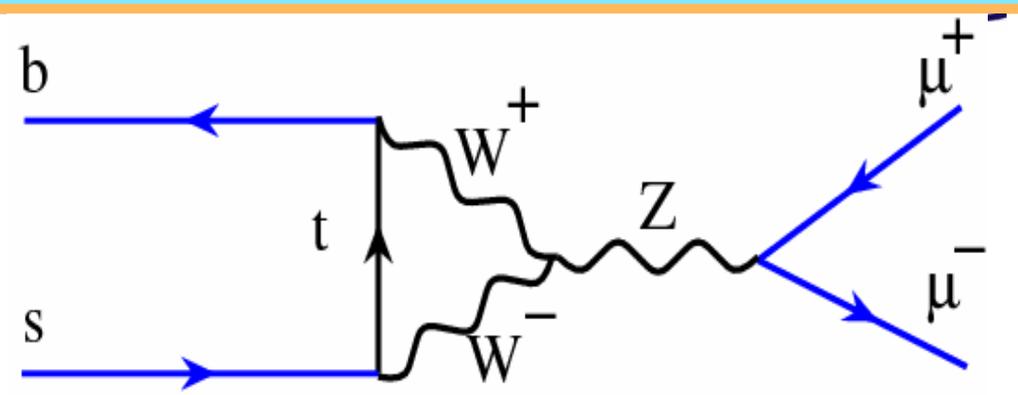


- D0 (1 June 2008) Delivered 4.22 fb^{-1} Recorded 3.66 fb^{-1}
- Expect 7-10 fb^{-1} by end of 2010

P5: Tevatron operation is expected to overlap for at least one year with physics operation of LHC. This overlap will be longer in favourable funding scenario.
Most probable time for a decision about 2010 run is spring of 2009

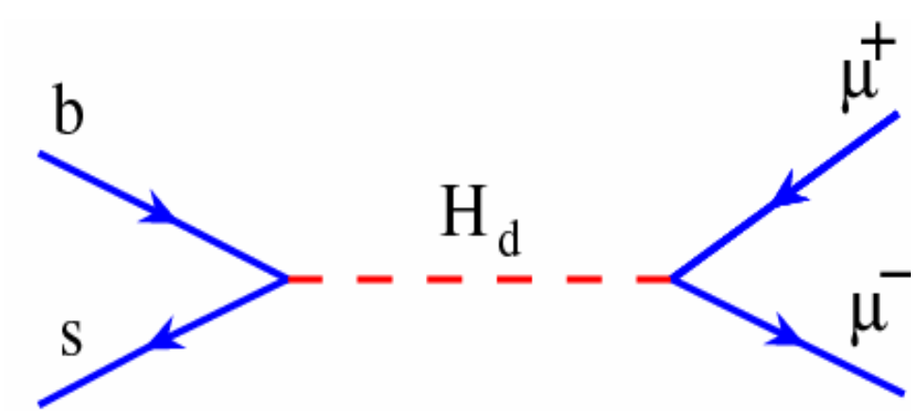
$B^0_s \to \mu^+\mu^-$

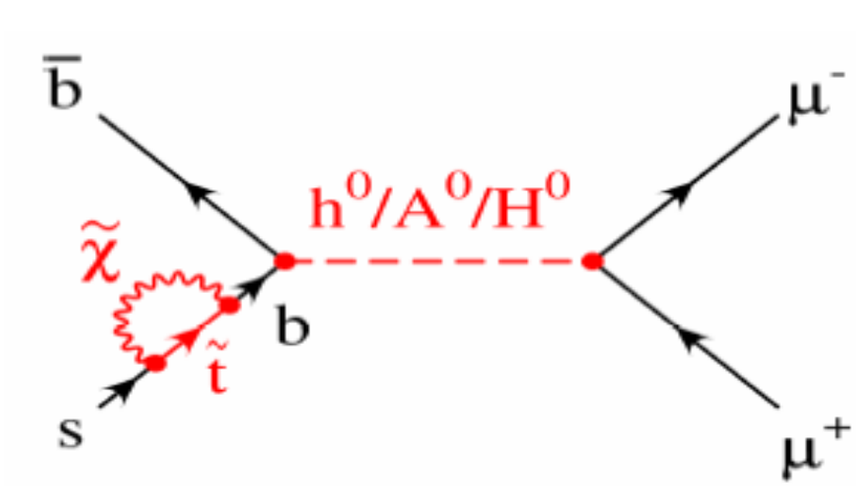




- $Br(B^0_s \to \mu^+\mu^-) = (3.42 \pm 0.54)\times10^{-9}$ *Buras, PLB 566, 115 (2003)*
  $Br(B^0_d \to \mu^+\mu^-) = (1.00 \pm 0.54)\times10^{-9}$ suppressed by $(V_{td}/V_{ts})^2$

- Expect 0 Events at Tevatron
- New Physics Contributions
  - MSSM ~$\tan^6(\beta)$, for large $\tan(\beta)$,
    SUSY with R-parity violation, Z' with off diagonal couplings, ...



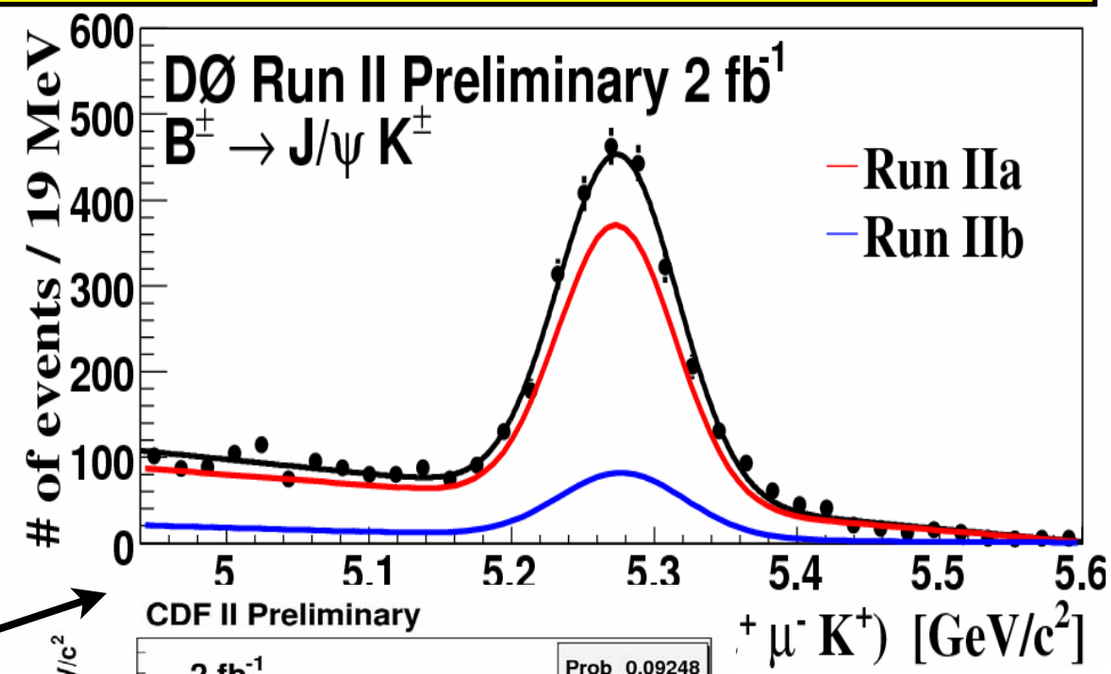


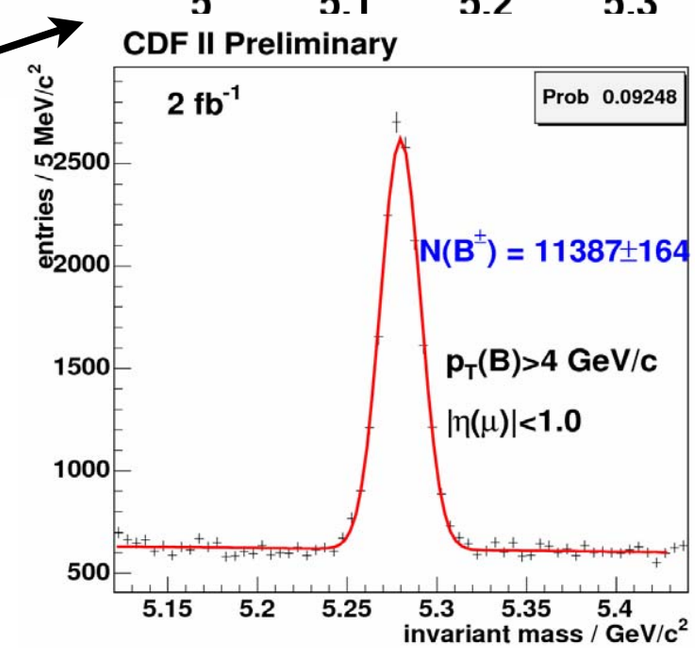
Analysis Steps - Example

$$\mathrm{BR}\left(\mathrm{B_s} \to \mu^+\mu^-\right) = \frac{N_{B_s}}{N_{B^+}} \frac{\alpha_{B^+} \cdot \epsilon_{B^+}}{\alpha_{B_s} \cdot \epsilon_{B_s}} \frac{f_{b\to B^+}}{f_{b\to B_s}} \mathrm{BR}\left(\mathrm{B}^+ \to \mathrm{J\Psi K}^+\right) \mathrm{BR}\left(\mathrm{J\Psi} \to \mu^+\mu^-\right)$$

Reduce Background, keep efficiency high

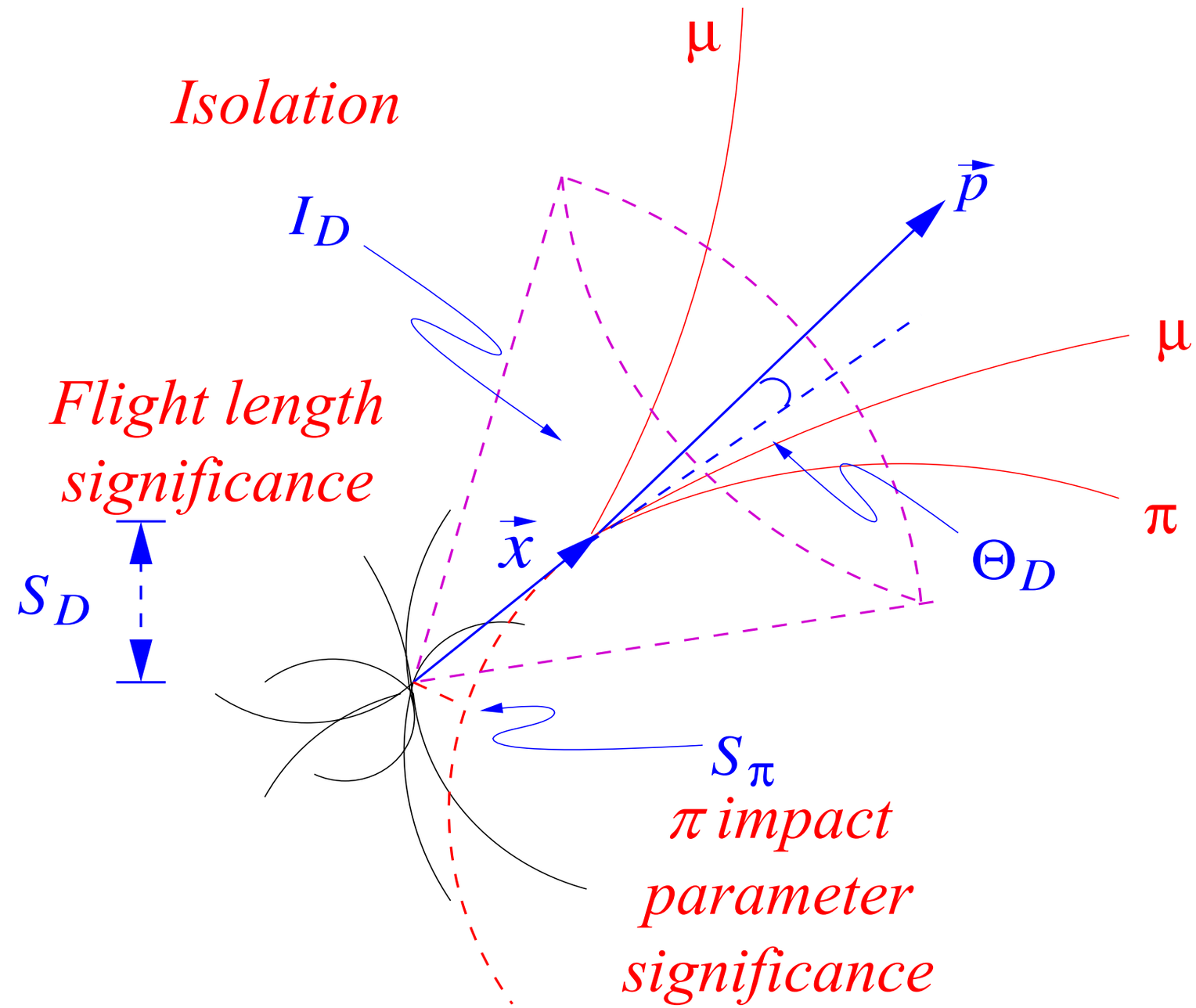
1. Pre-selection cuts to reduce obvious backgrounds
2. Optmization (signal efficiency and expected background)
   Blind analysis
3. Reconstruct $B^+ \to J/\Psi\ K^+$ normalisation mode
4. Open the box → Answer



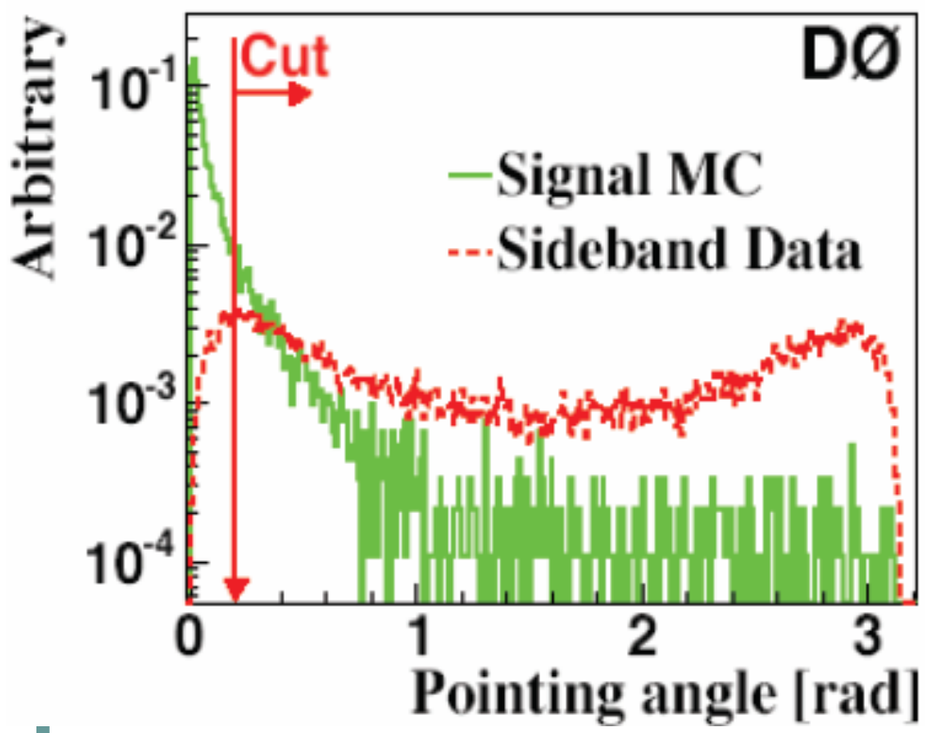


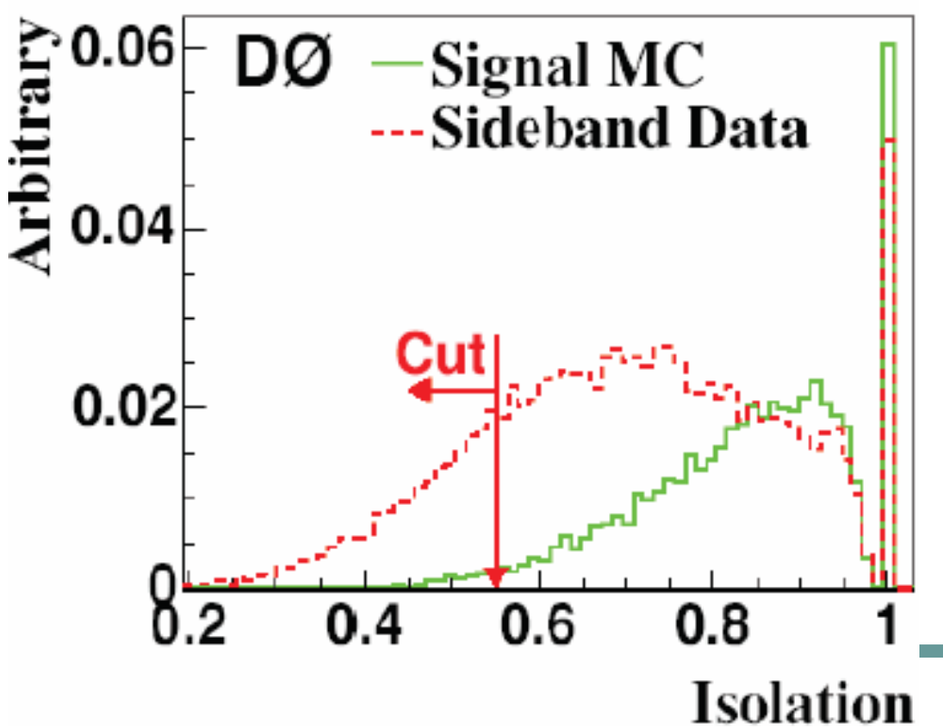
Discriminating Variables

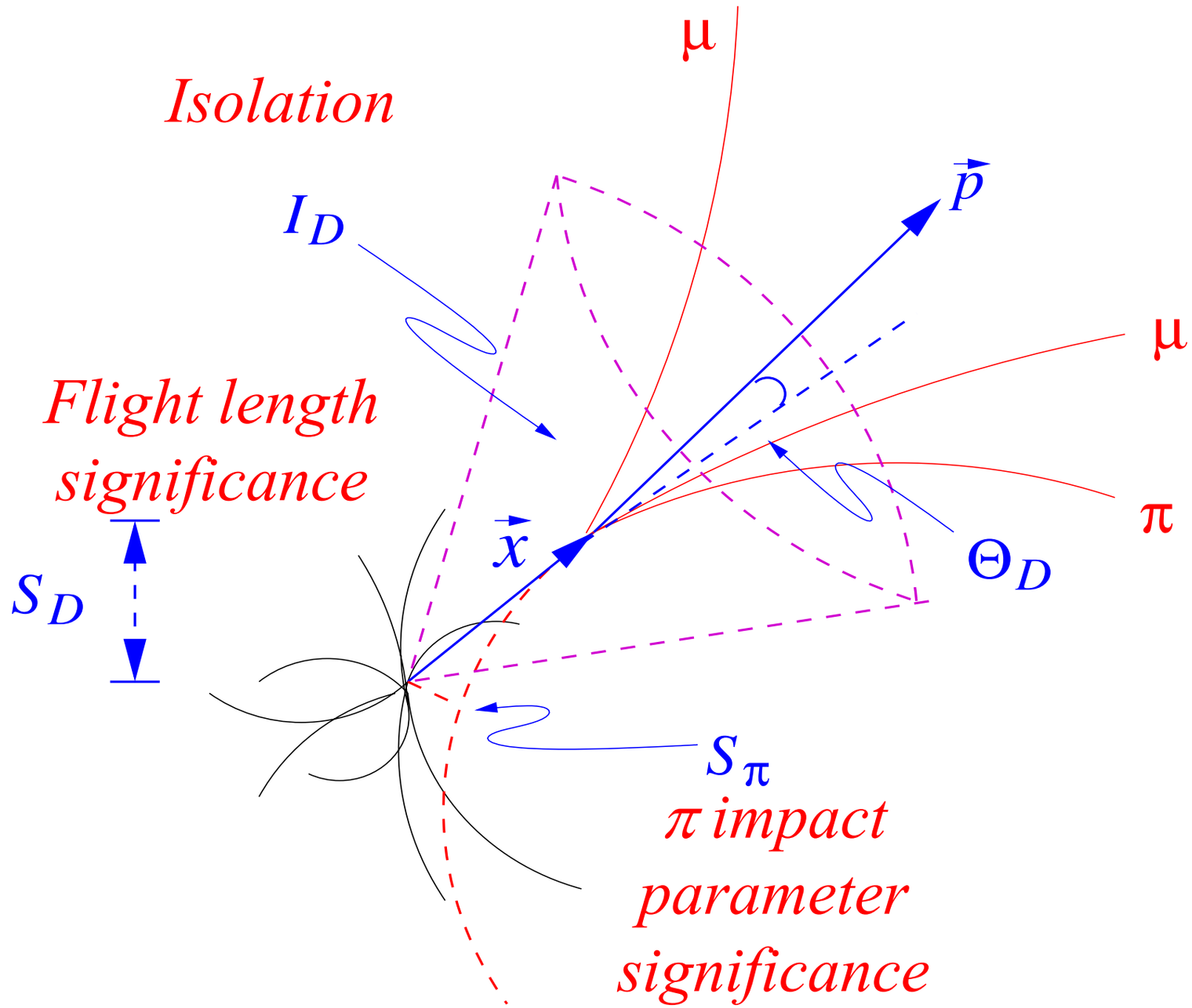
- $\mu^+\mu^-$ mass
  ~ ±2.5σ mass window
- B vertex displacement
- Isolation
  fraction of pT from
  $B \rightarrow \mu\mu$ within
  $\Delta R=(\Delta\eta^2+\Delta\varphi^2)^{1/2}$
- Decay length
  significance
- $P_T(B)$ & $P_T(\mu)$



Discriminating Variables

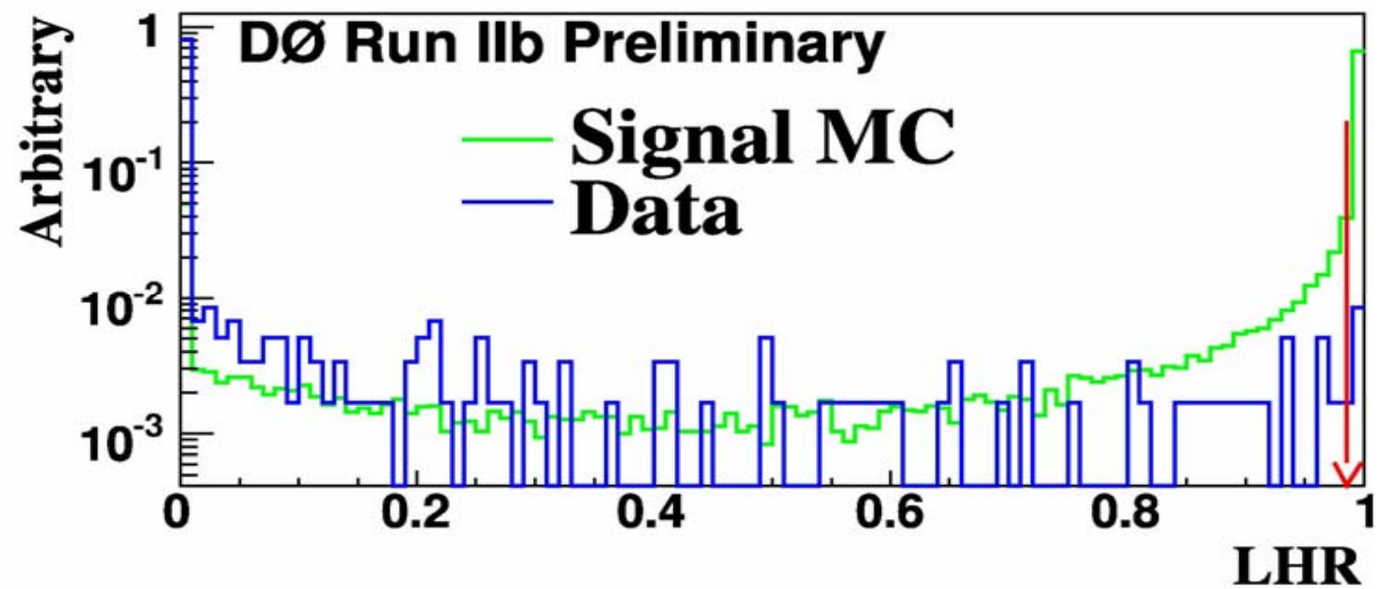


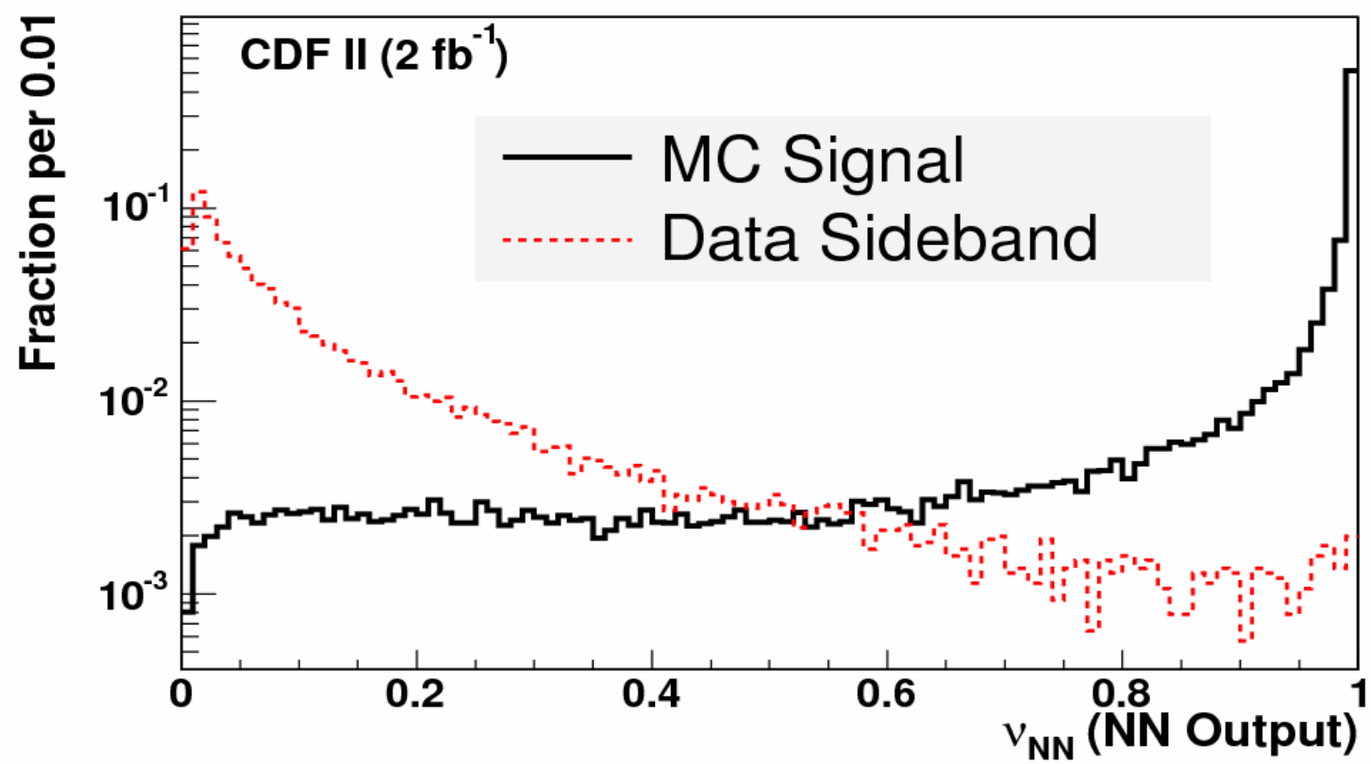




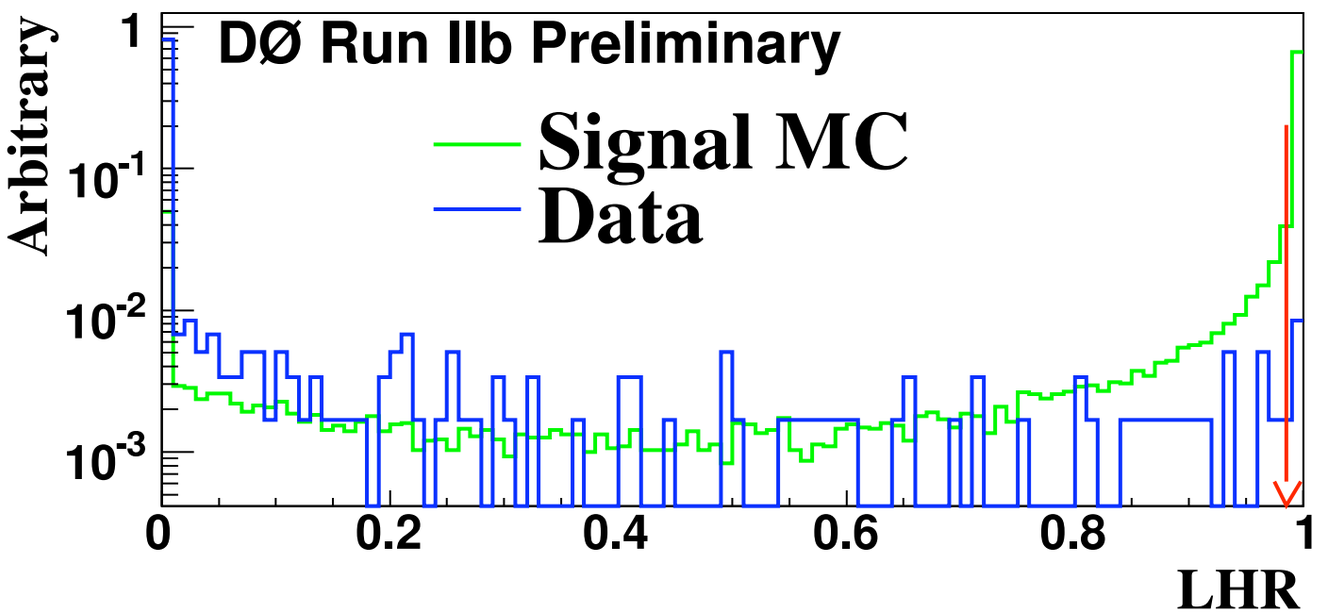
$B^0_s \rightarrow \mu^+\mu^-$ Selection and Optimization

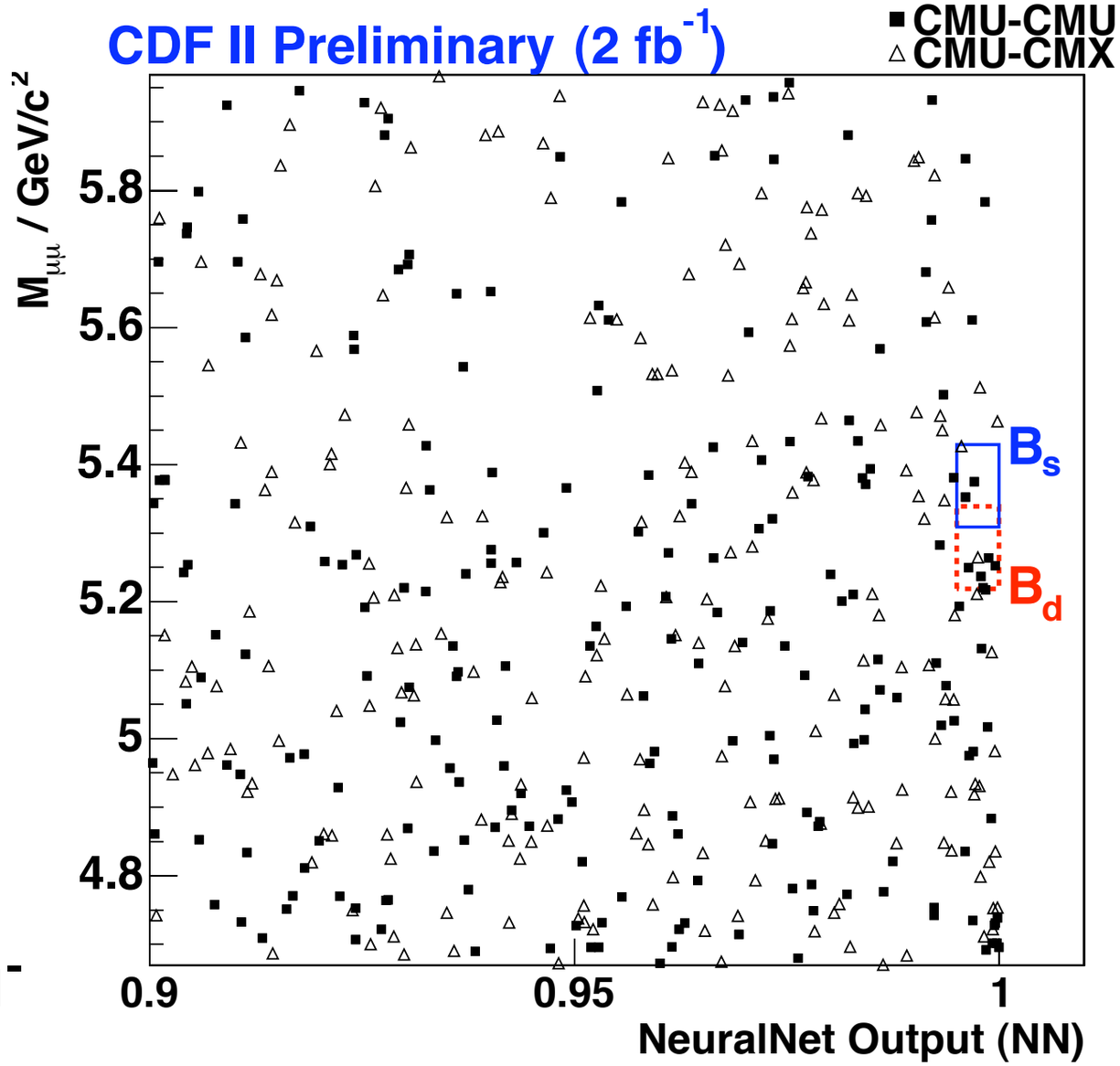
- Signal: MC
- Background: data mass sidebands
- Final selection
  - Likelihood ratio (D0)
  - Neural network (CDF)
- Check selection with control samples
  - Misidentified muon
  - Same sign muons





Results





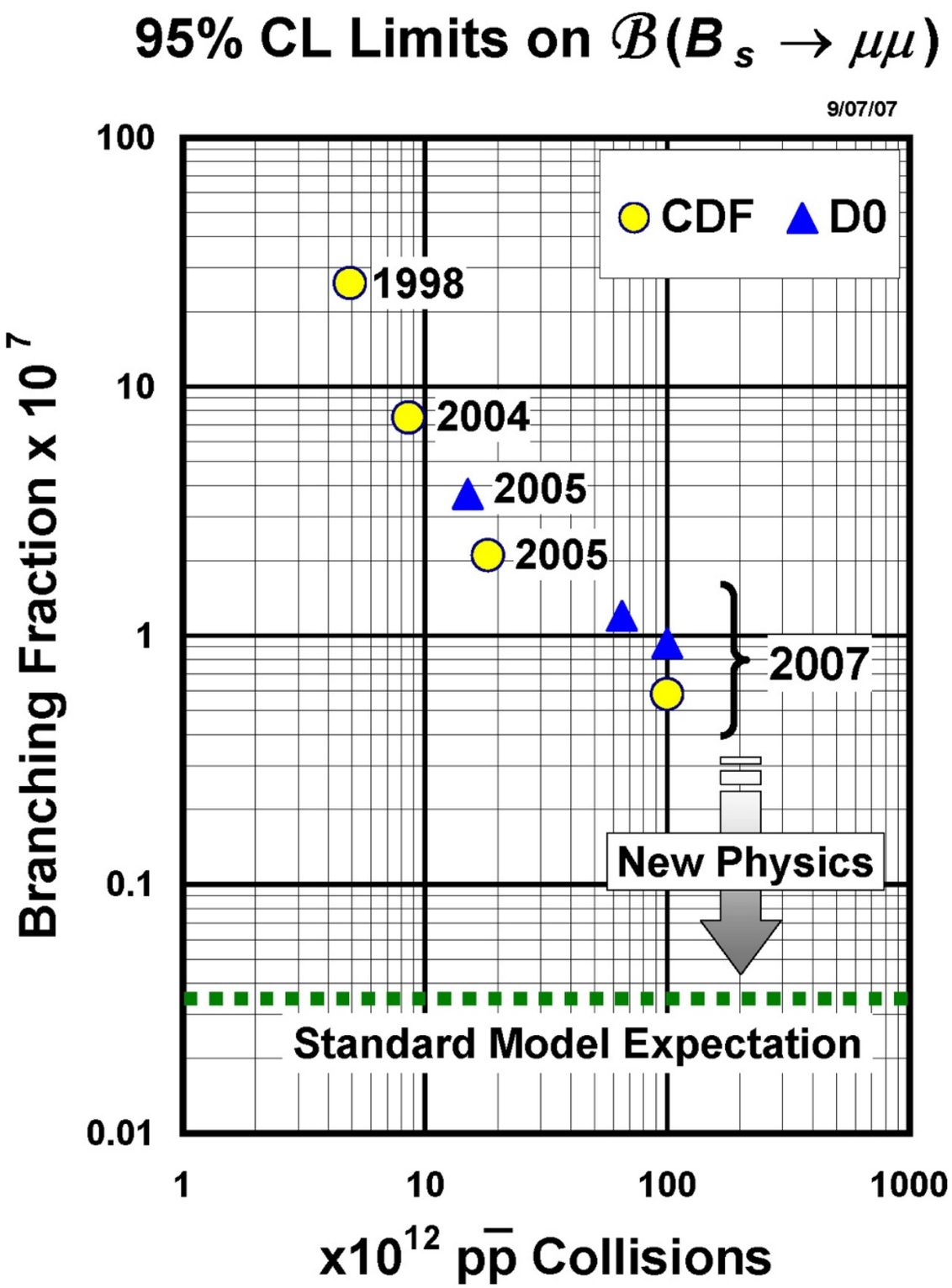
- No excess observed (2 fb^{-1})

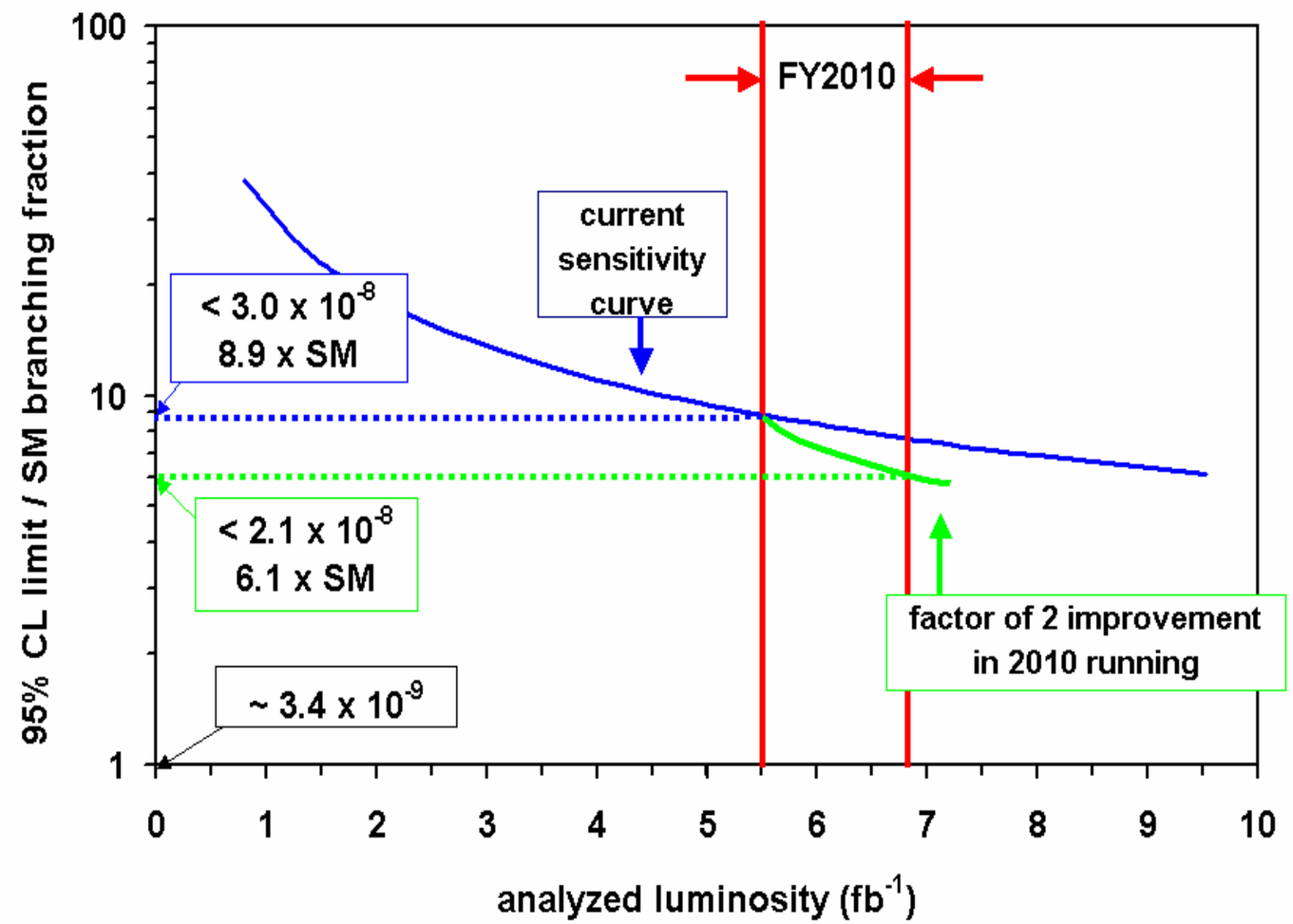
90% Confidence limits on BR

	$B^0_s \to \mu^+\mu^-$	$B^0_d \to \mu^+\mu^-$
CDF PRL 100,101802 (2008)	$< 4.7\ 10^{-8}$	$< 1.5\ 10^{-8}$
D0	$< 7.3\ 10^{-8}$	

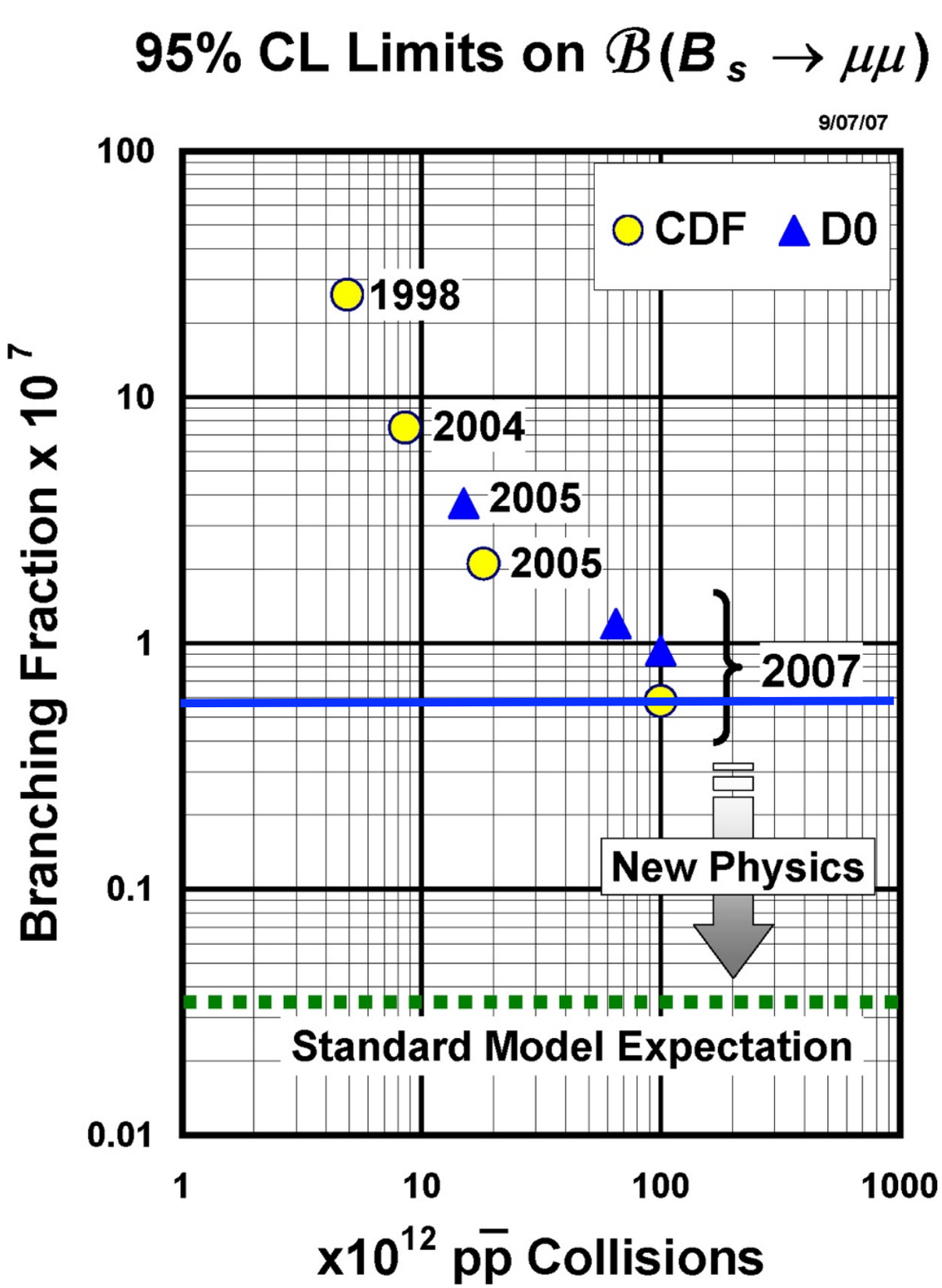
HFAG Average:
$< 4.7\ 10^{-8}$

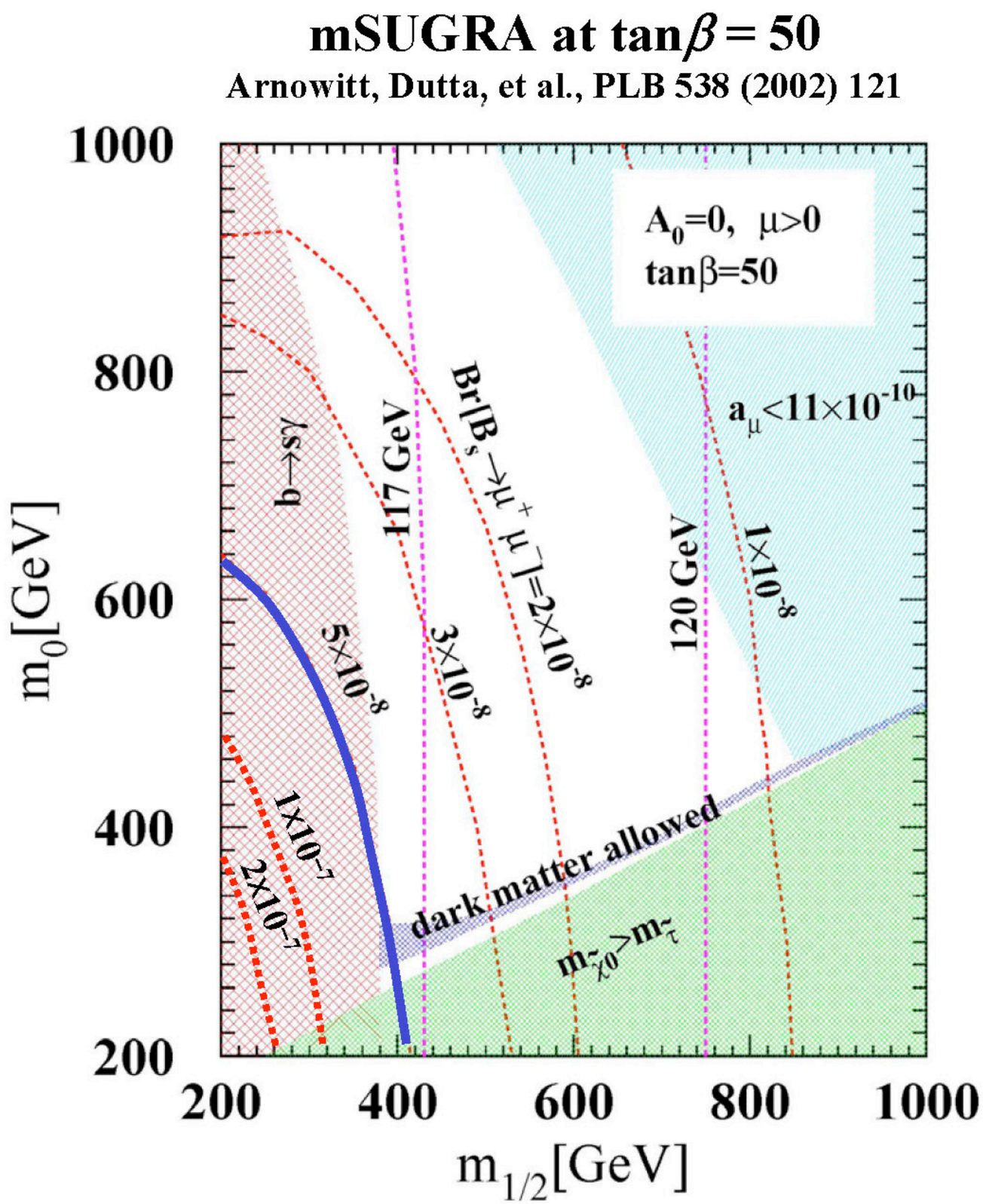
History & Future





mSUGRA Limits





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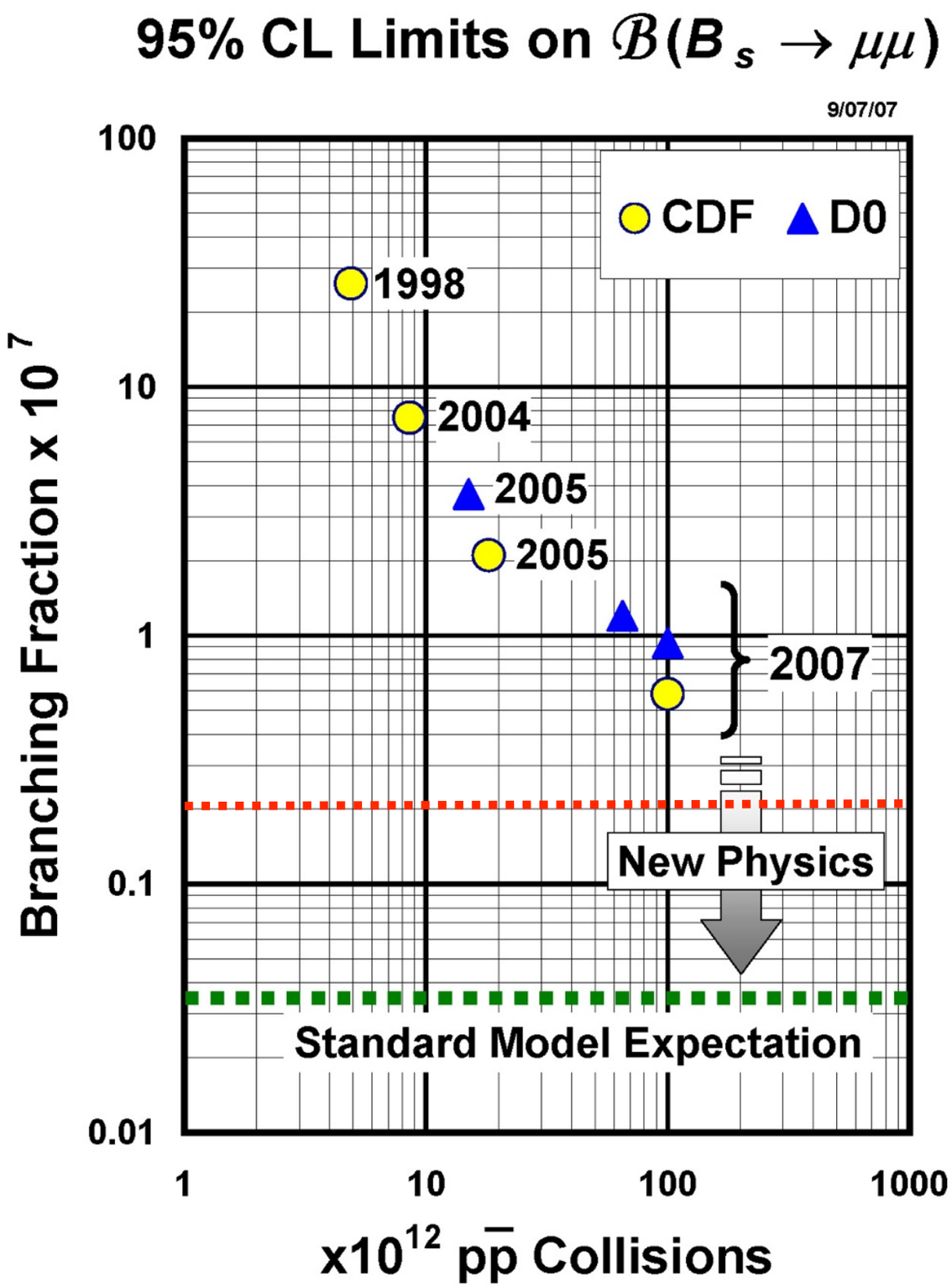
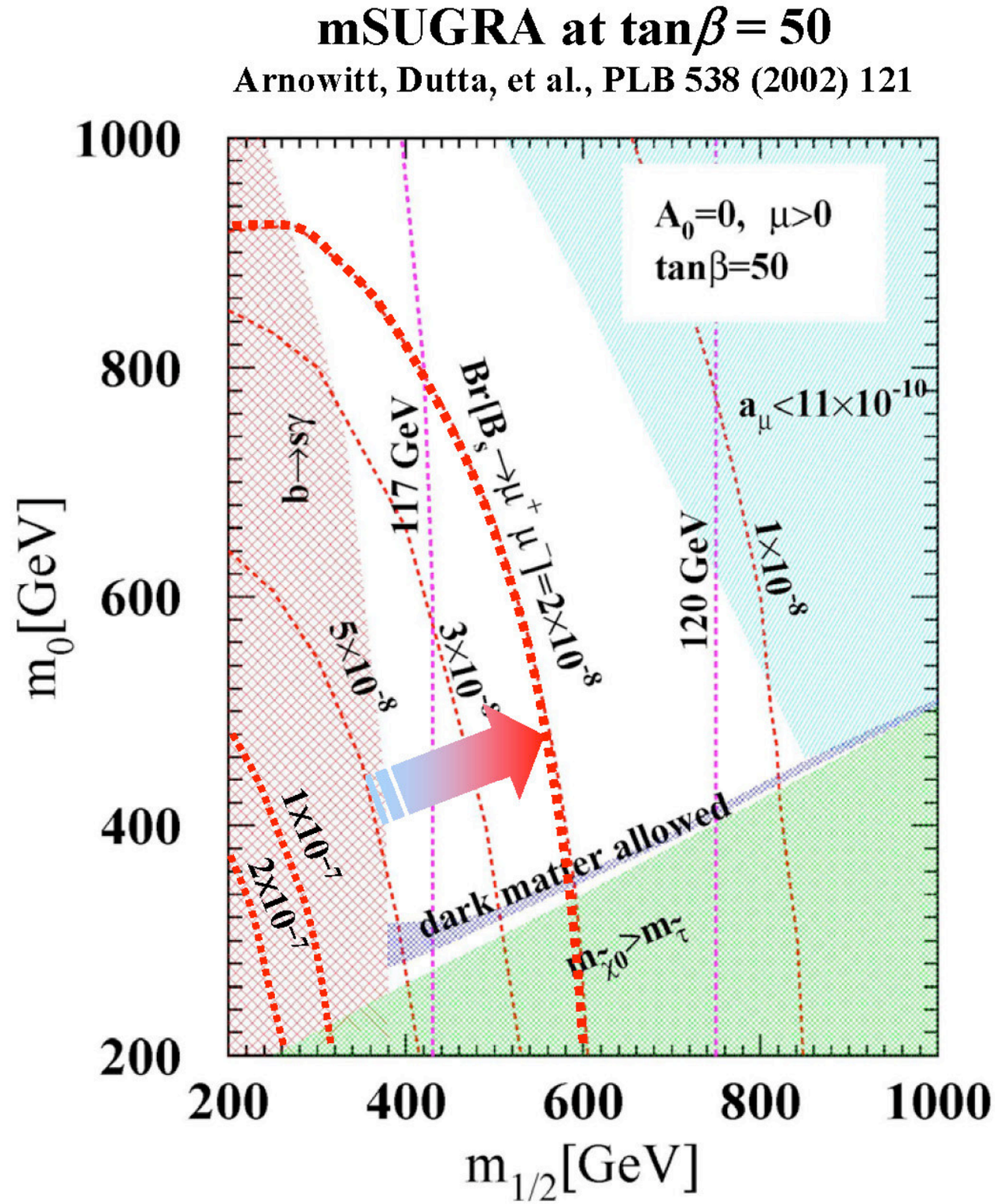
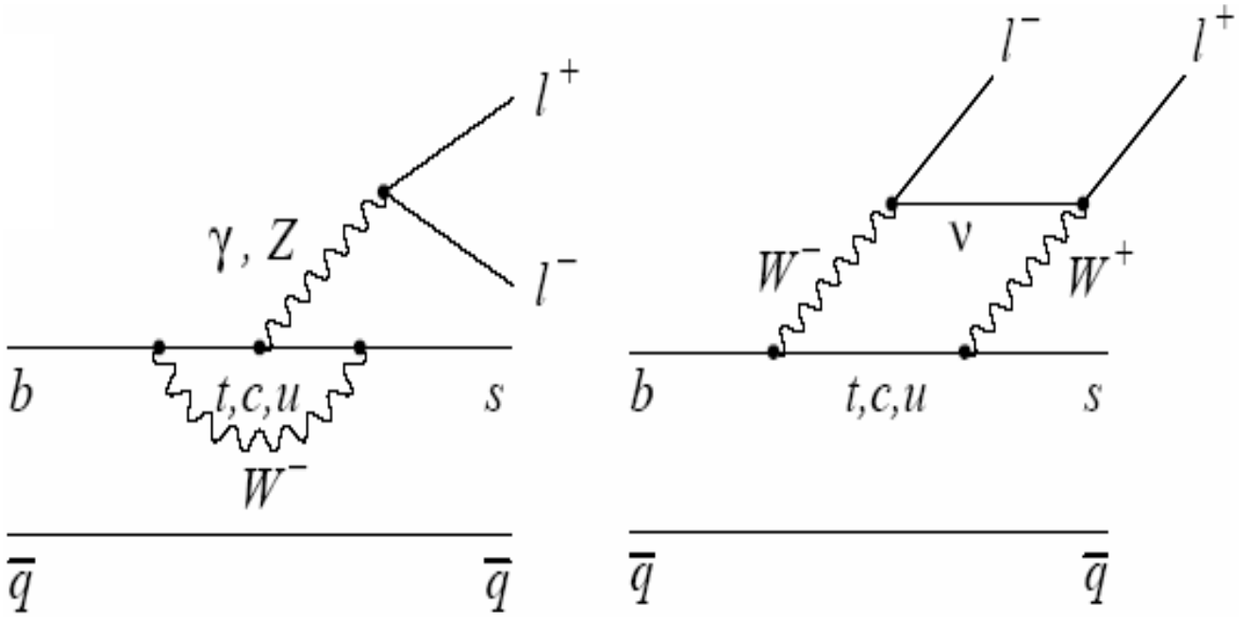
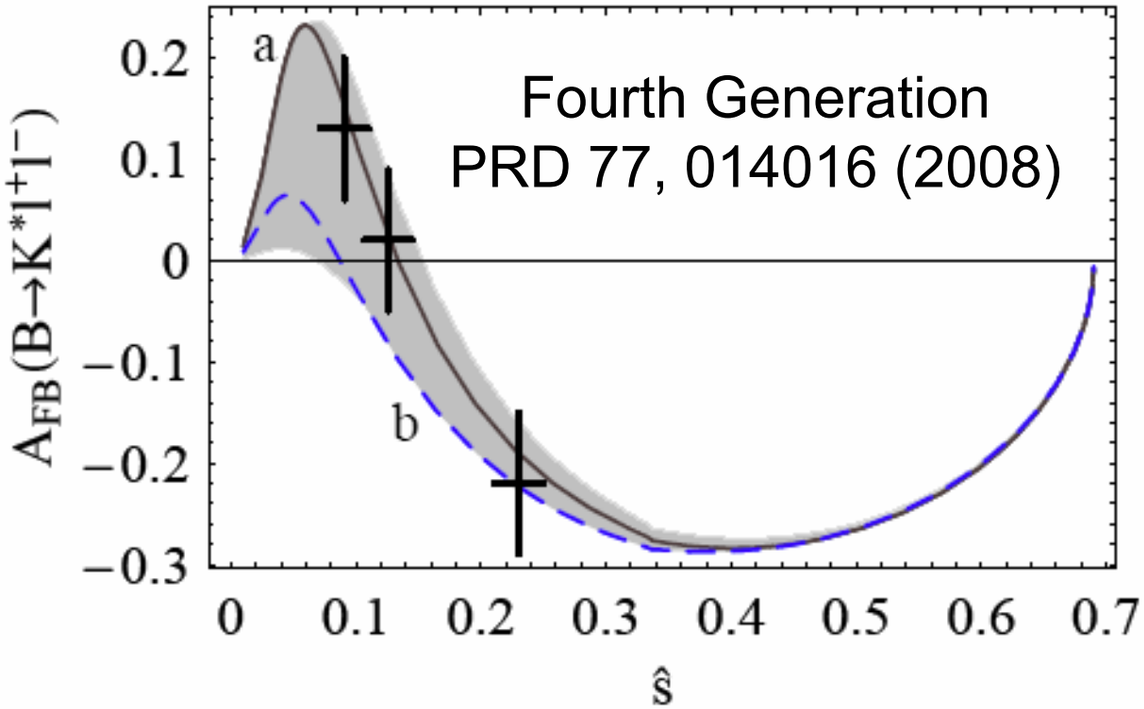




$B^{(\pm,0)}_{(s)} \rightarrow h^{(\pm,0)}\mu^+\mu^-$

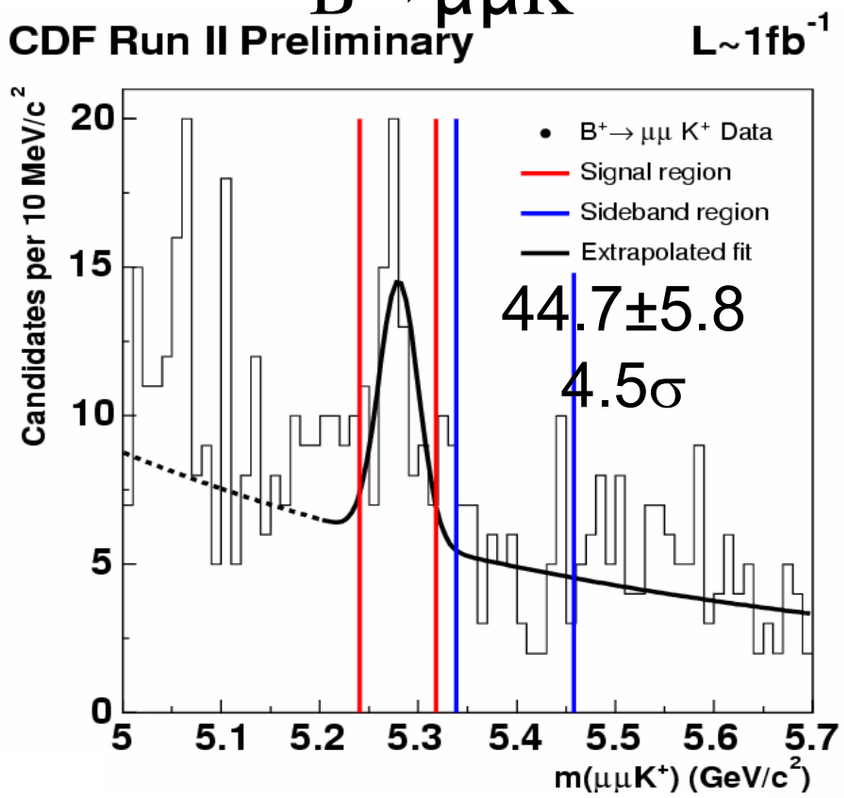
- Non resonant decays via box or penguin diagrams
- BaBar/Belle:
  $B^{\pm} \rightarrow K\mu^+\mu^-$ PRD73, 092001 (2006)
  $B^0_d \rightarrow K^*\mu^+\mu^-$ PRL96, 251801 (2006)
- Not yet observed:
  $B^0_s \rightarrow \varphi\mu^+\mu^-$
- Predicted branching ratio 1.6×10^{-6}
- NP:
  Larger BR, modified kinematic distributions



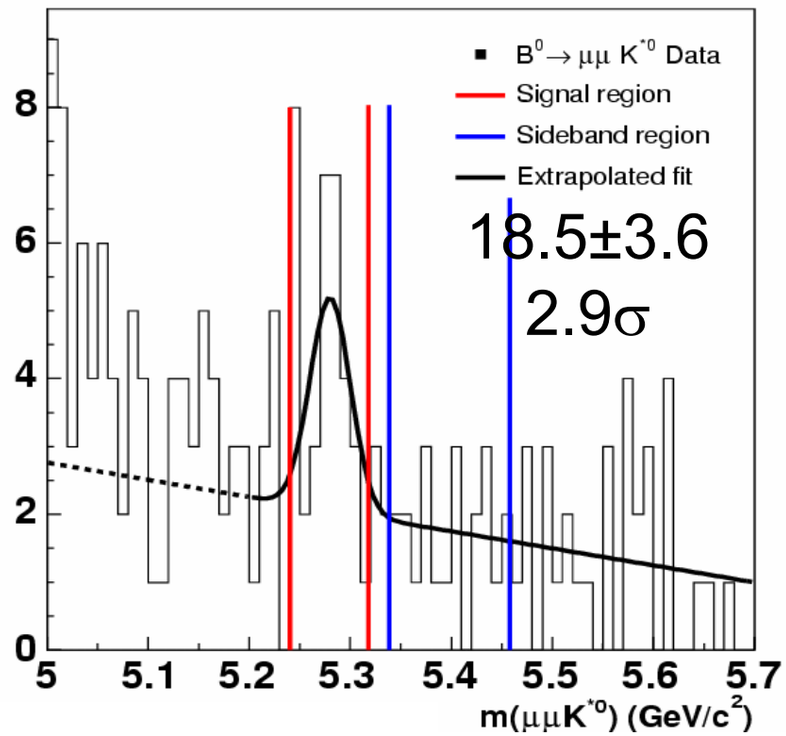


$B^{(\pm,0)}_{(s)} \rightarrow h^{(\pm,0)}\mu^+\mu^-$

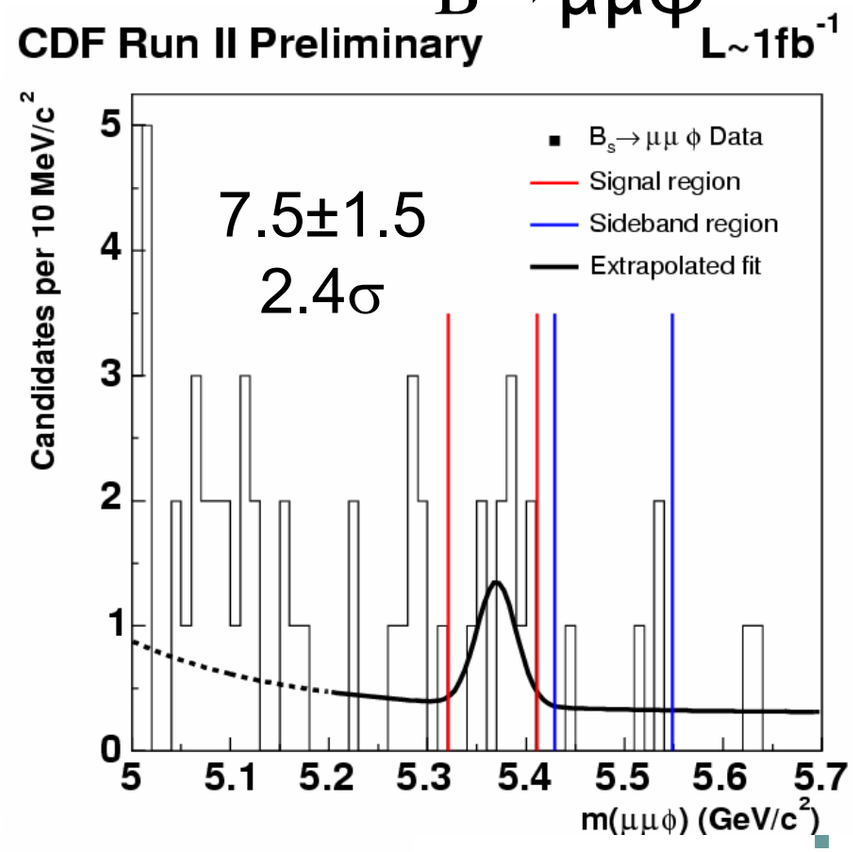
$B \rightarrow \mu\mu K^+$

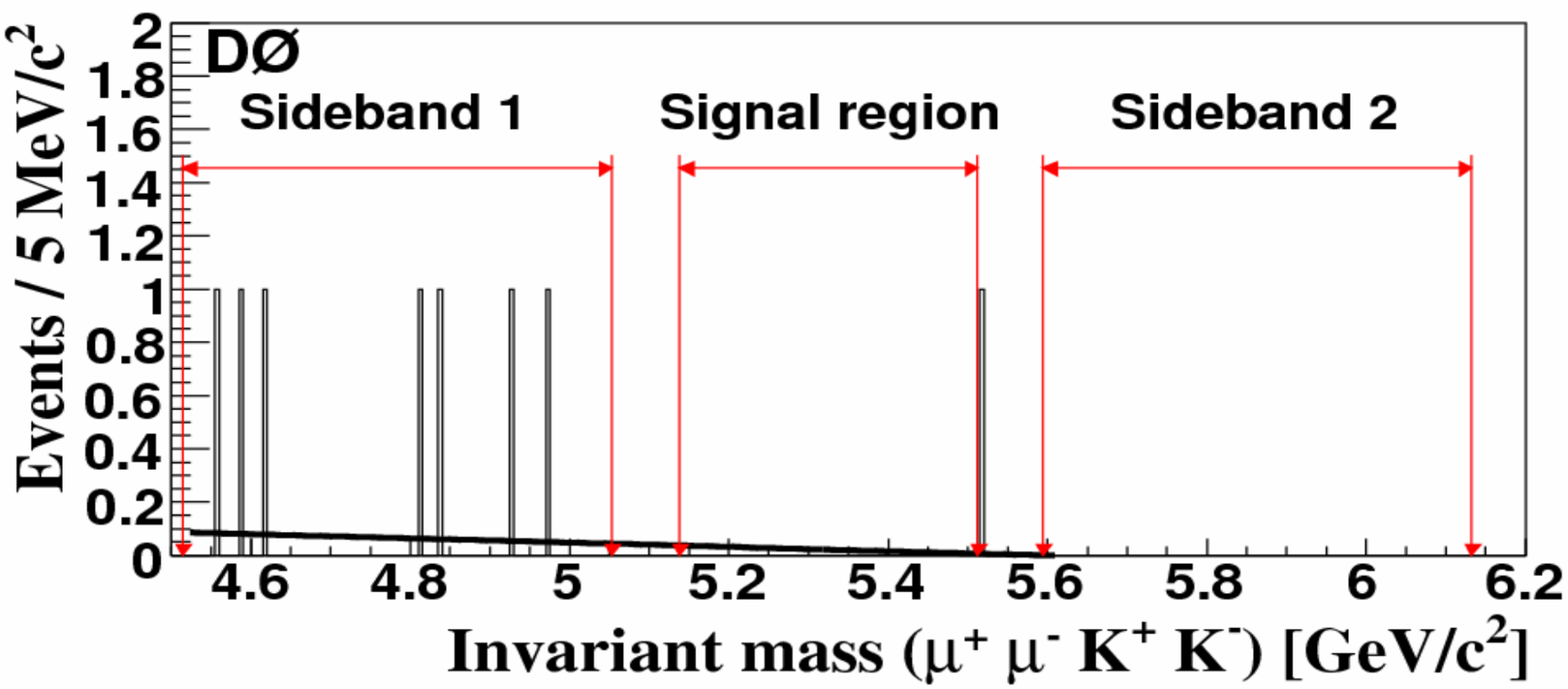


$B \rightarrow \mu\mu K^*$

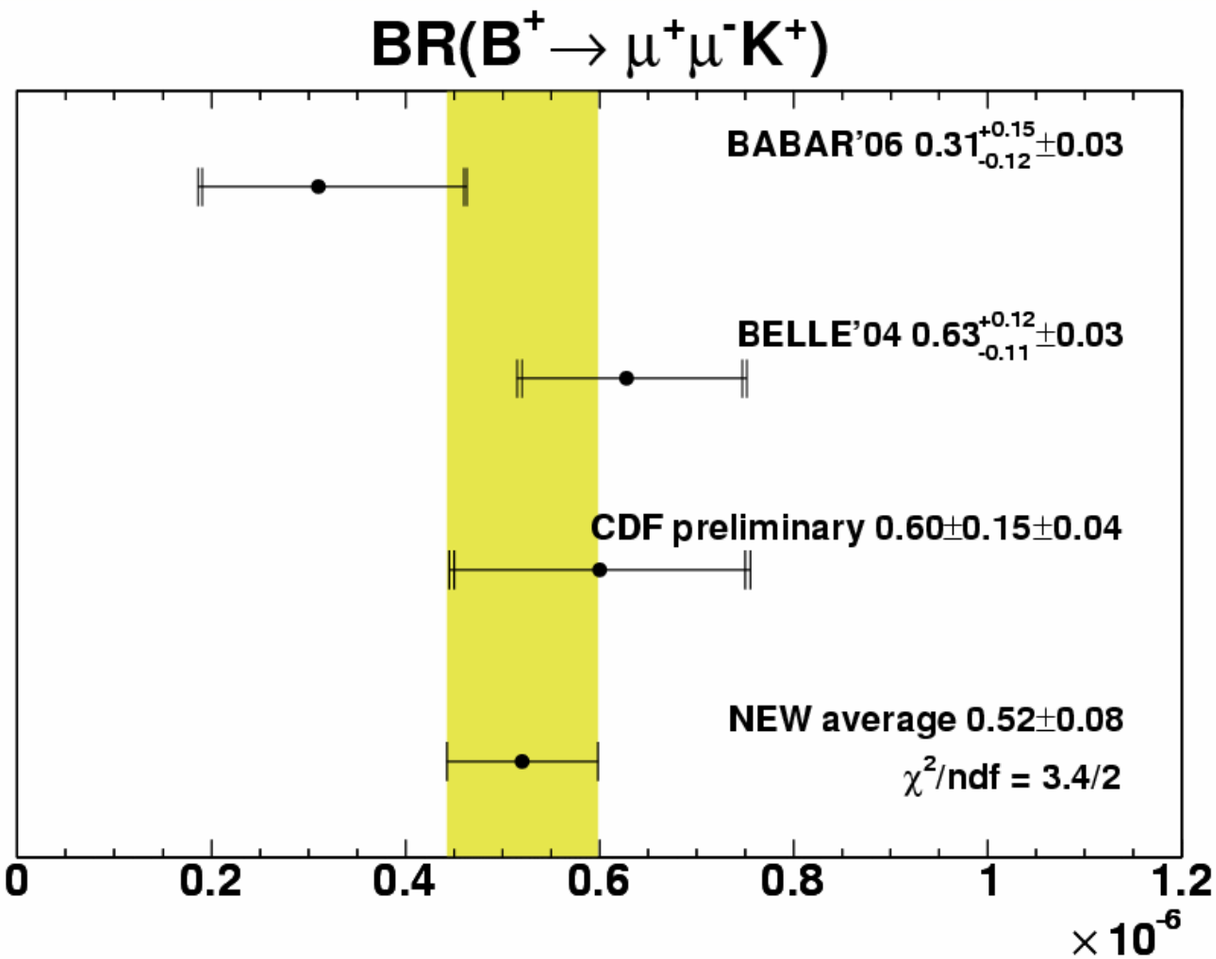


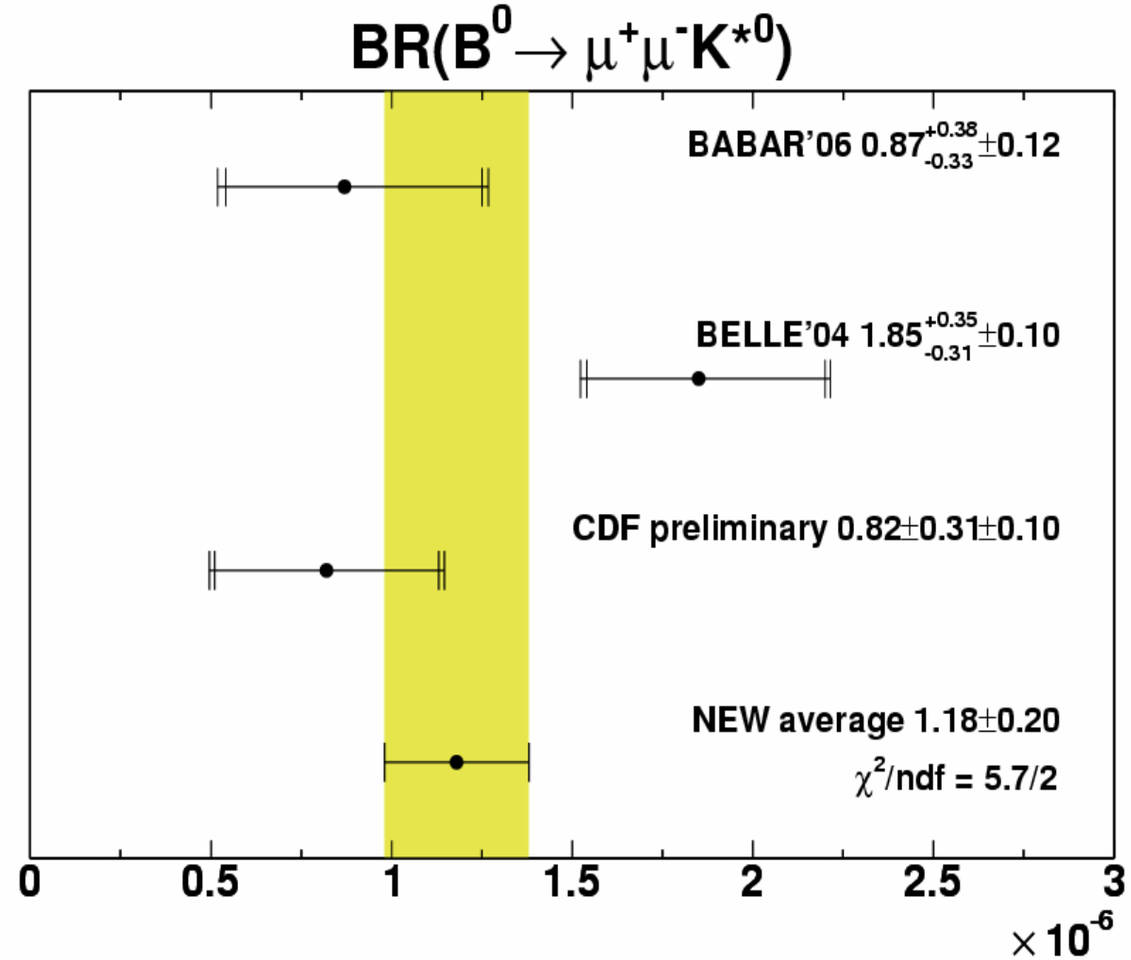
$B \rightarrow \mu\mu\varphi$





$B^{(\pm,0)}_{(s)} \rightarrow h^{(\pm,0)}\mu^+\mu^-$





- $BR(B^0_s \rightarrow \varphi\mu^+\mu^-)$ @ 90% CL

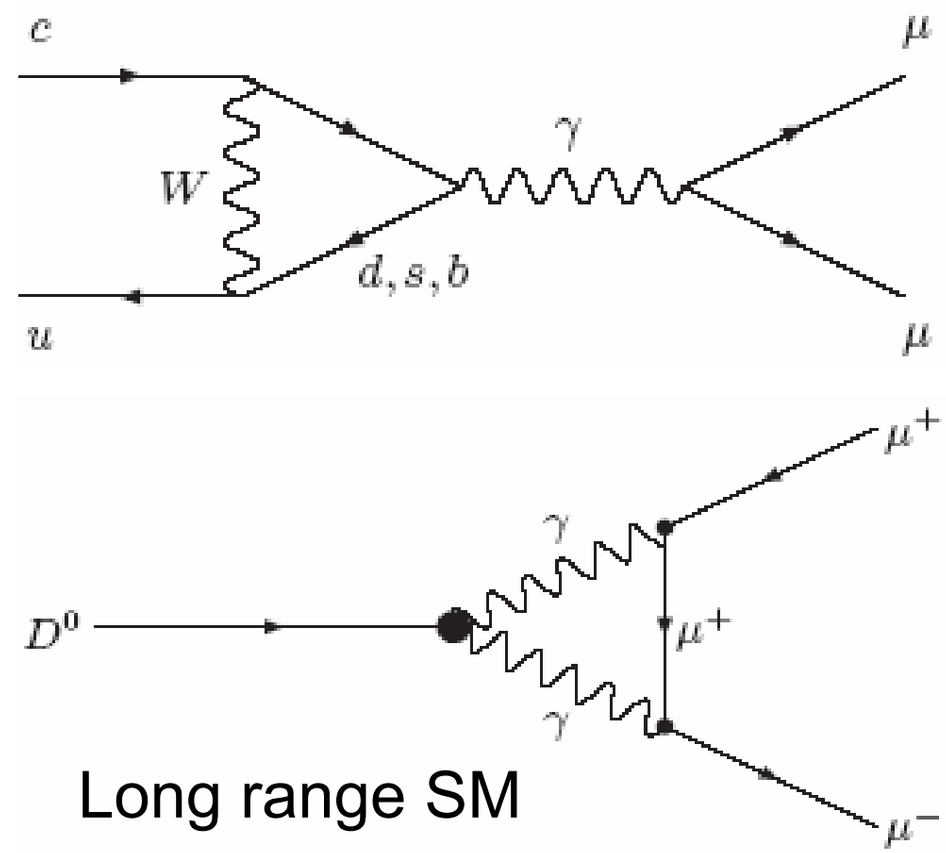
  CDF(hep-ex/0804.3908) $< 5.0\times10^{-6}$
  D0 (PRD 74 , 031107 (2006)) $< 3.2\times10^{-6}$

Prediction
1.6×10^{-6}

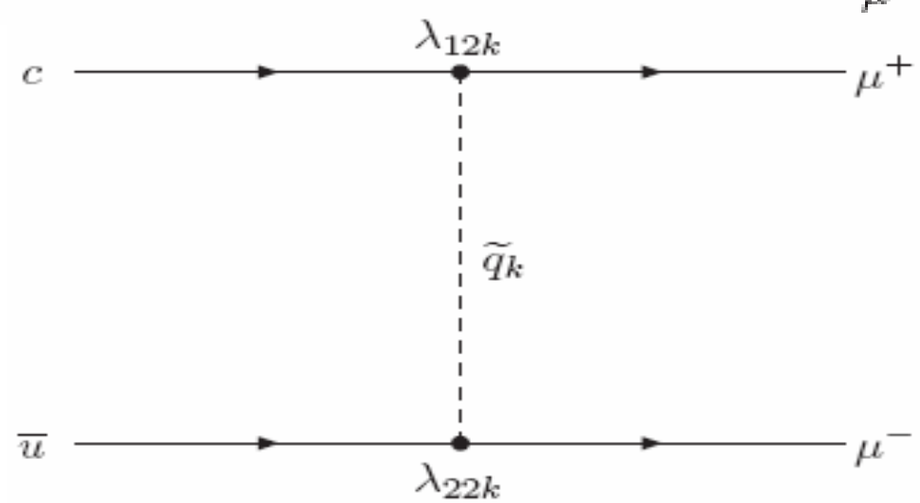
$D^0 \to \mu^+\mu^-$

- B0s→μ+μ- vs D0→μ+μ-
  - down quark sector vs up quark sector
- Short range contribution to BR is ~10^{-18}
  - suppressed by GIM
- Long range contribution to BR is ~ 4×10^{-13}

  Burdmanet al. hep-ph/0112235
- Significant enhancement possible in SUSY with R-parity violation

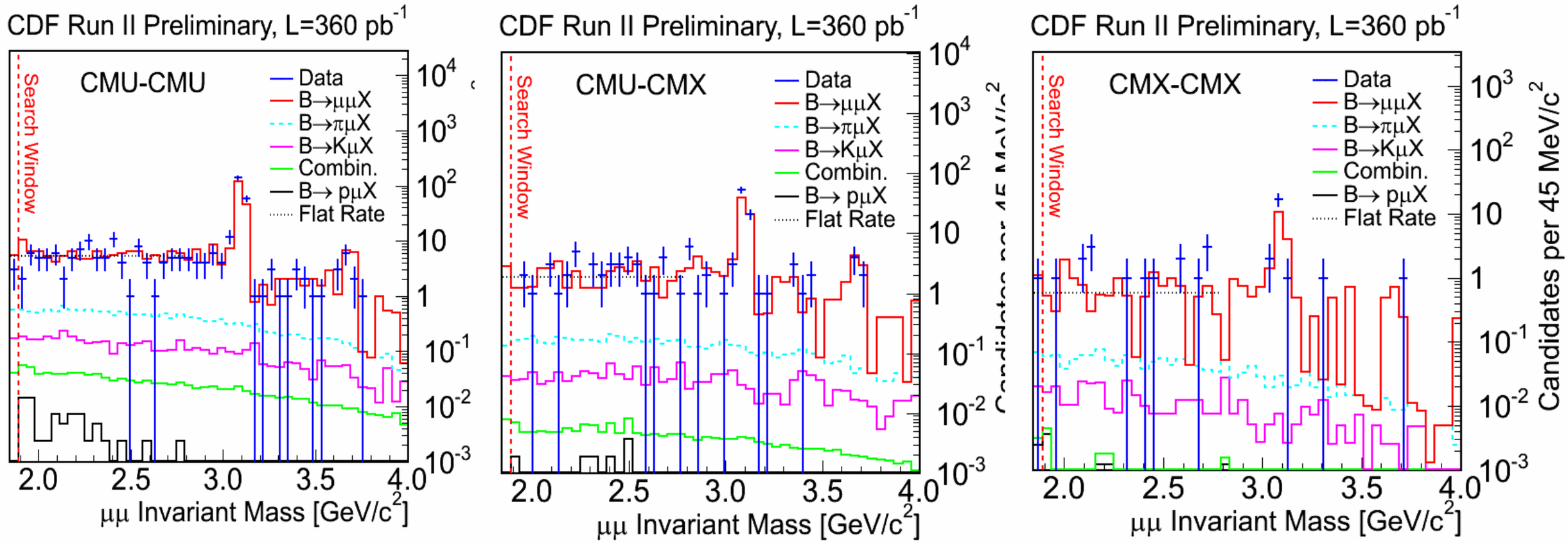


Long range SM



SUSY with R-parity violation

$D^0 \rightarrow \mu^+\mu^-$

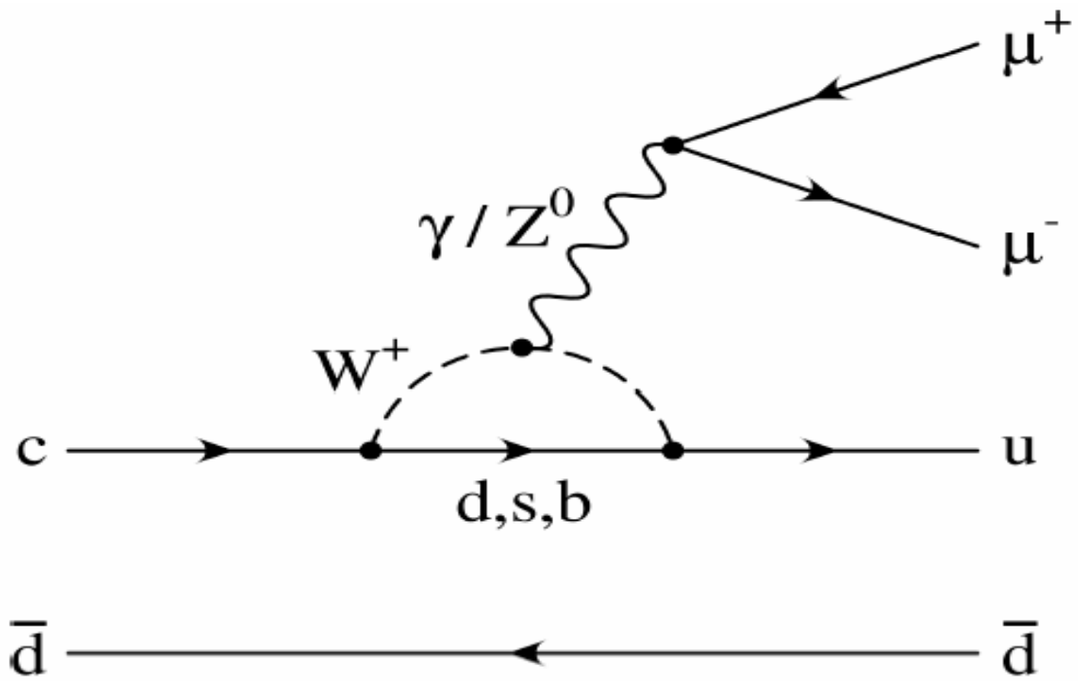


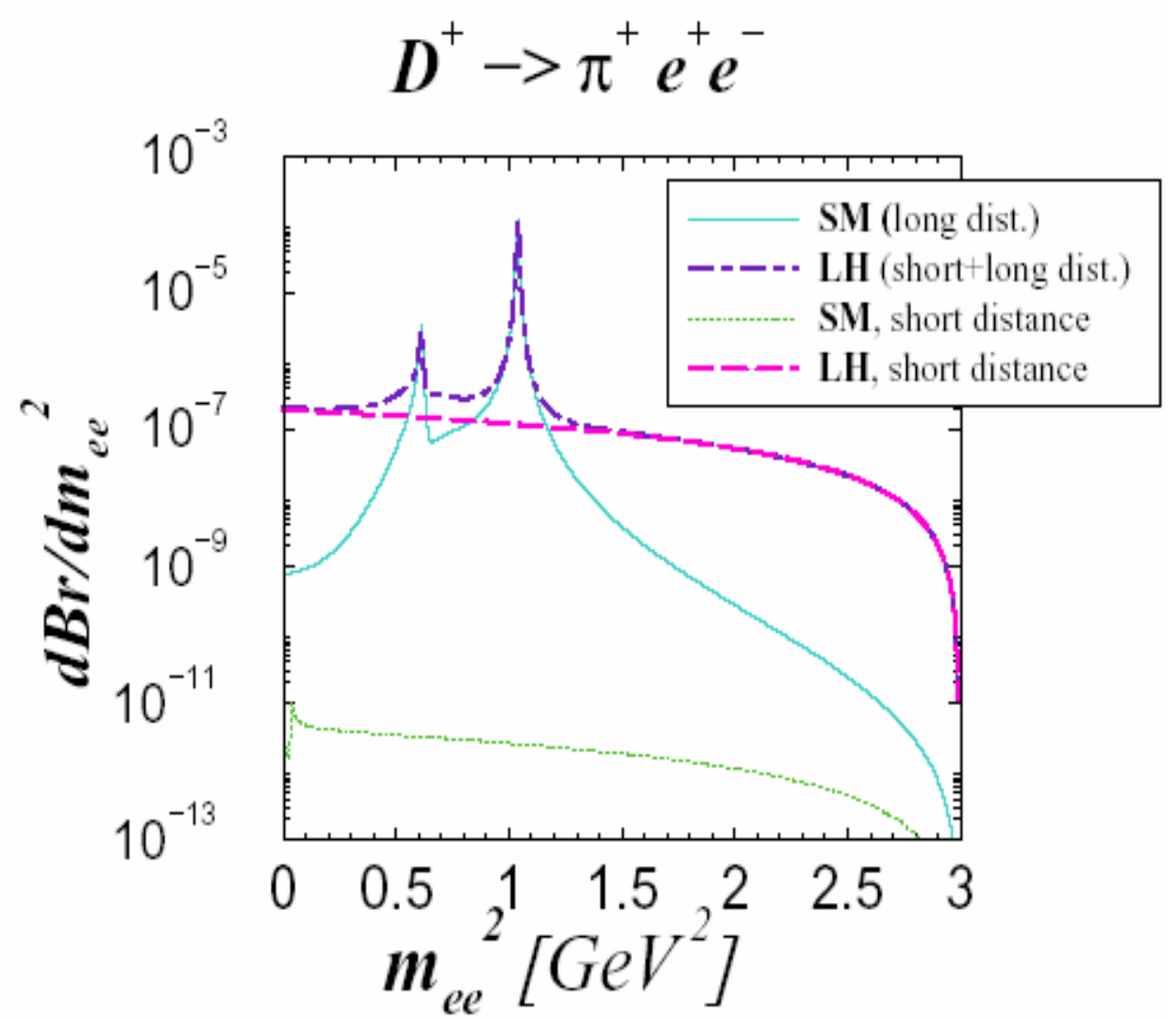
Detector	CMU-CMU	CMU-CMX	CMX-CMX
Expected Background	4.9±1.3	2.7±1.0	1.0±0.5
Signal	3 (p=0.3)	0 (p=0.11)	1 (p=0.7)

$$BR(D^0 \rightarrow \mu^+\mu^-) < 4.3 \times 10^{-7} \text{ at } 90\% \text{ CL}$$

$$\lambda_{21k}\lambda_{22k} = 1.5\sqrt{BR(D^0 \rightarrow \mu^+\mu^-)} < 9.8 \times 10^{-4}$$

$D_{(s)}^+ \to \pi\mu^+\mu^-$





- Orthogonal to $B^0_s \to \mu^+\mu^-$
  - Effects in up quark sector
- Long distance resonance production
  - BR = 1.9×10^{-6}

Little Higgs models with new up sector vector quark

Fajfer et al. hep-ph/0511048

RPV in the up sector and not the down sector

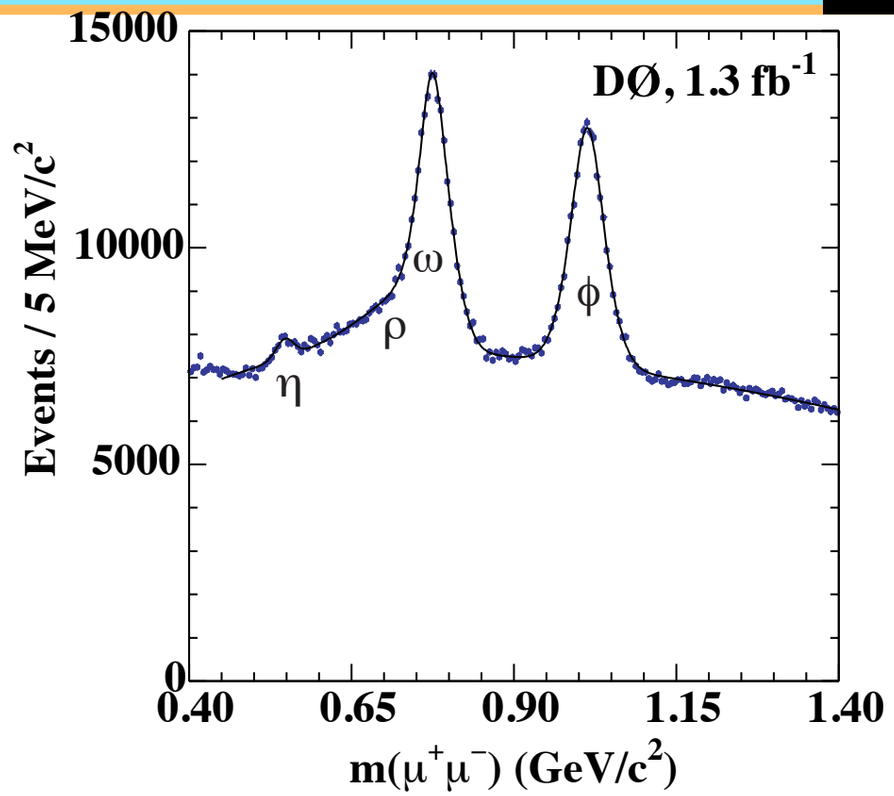
Burdman et al. hep-ph/0112235

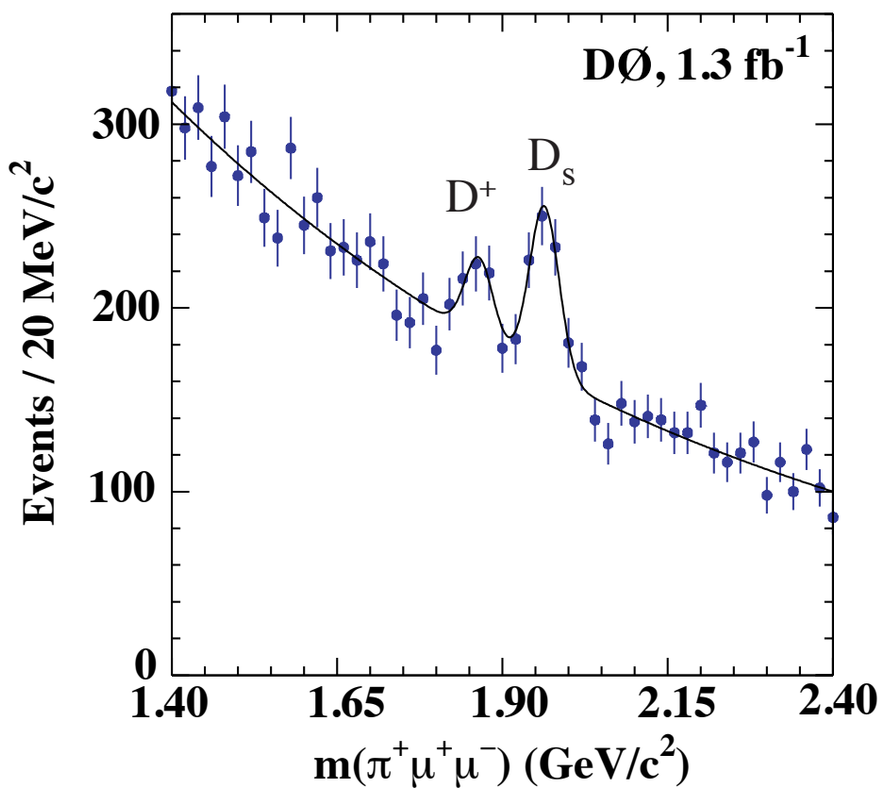
Resonant $D^+_{(s)}$ Decays

- Select events with m(μμ) in region of the φ mass
  - $N(D_s^+) = 254 \pm 36$
  - $N(D^+) = 115 \pm 31$

- Statistical Significance
  8σ for D_s^+ and 4.1σ for D^+
  - First observation of D_s^+
  - First evidence of D^+

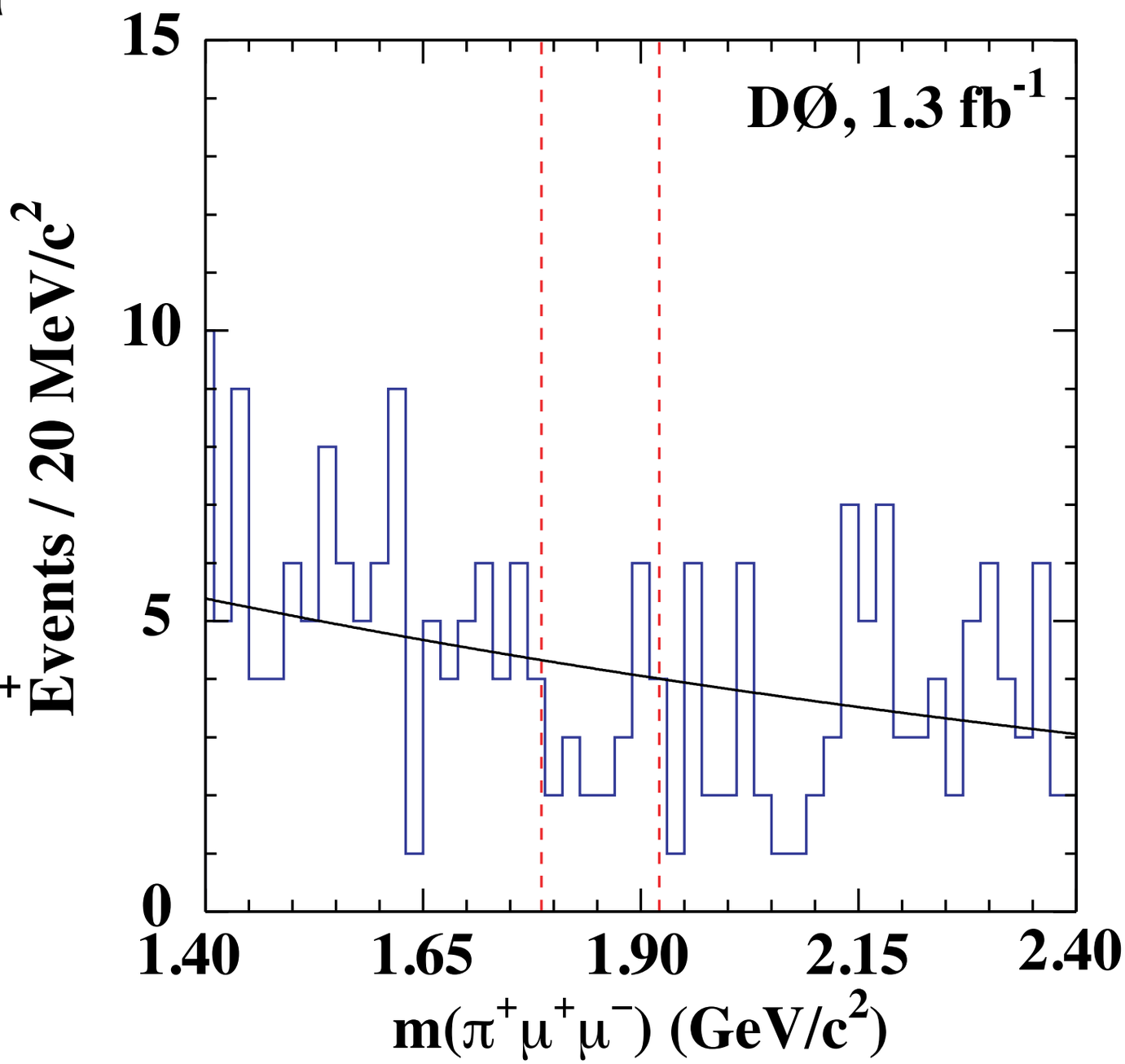
$$BR(D^+ \to \varphi\pi^+ \to \mu^+\mu^-\pi^+) = (1.8 \pm 0.5 \pm 0.6)\times 10^{-6}$$





Resonant $D^+_{(s)}$ Decays

- Exclude resonant $\varphi \to \mu\mu$ mass region
  - 19 candidates in D^+ region
  - Expect 25.8±4.6 background events (p-value=0.14)
  - Normalise to $D^+ \to \varphi\pi^+$
  - $BR(D^+ \to \mu\mu\pi^+)$ $< 3.9 \times 10^{-6}$ at 90% CL



The Last Word

- Measurement of Vts & Vtd now limited by theoretical inputs
  - Decade before significant improvement?
- B & D rare decays provide a sensitive probe into new physics
  - Sensitive to theoretical predictions in several extensions to the standard model.
  - Complementary to direct searches
  - D0 & CDF will make major inroads before the LHC gets up and running
- Significant improvements expected with data set that should increase by a factor of 4