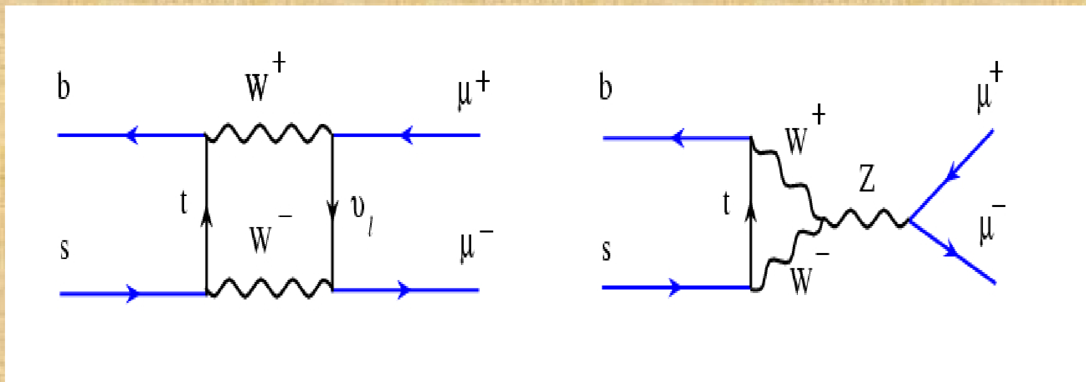
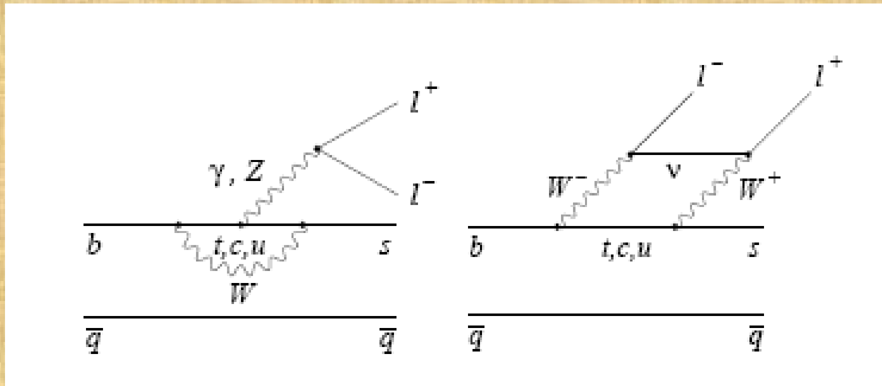
Rare Decays at Tevatron



Topics: 1)B→μμ search at Tevatron

2) b→sl^+l^- at Tevatron



Marco Rescigno

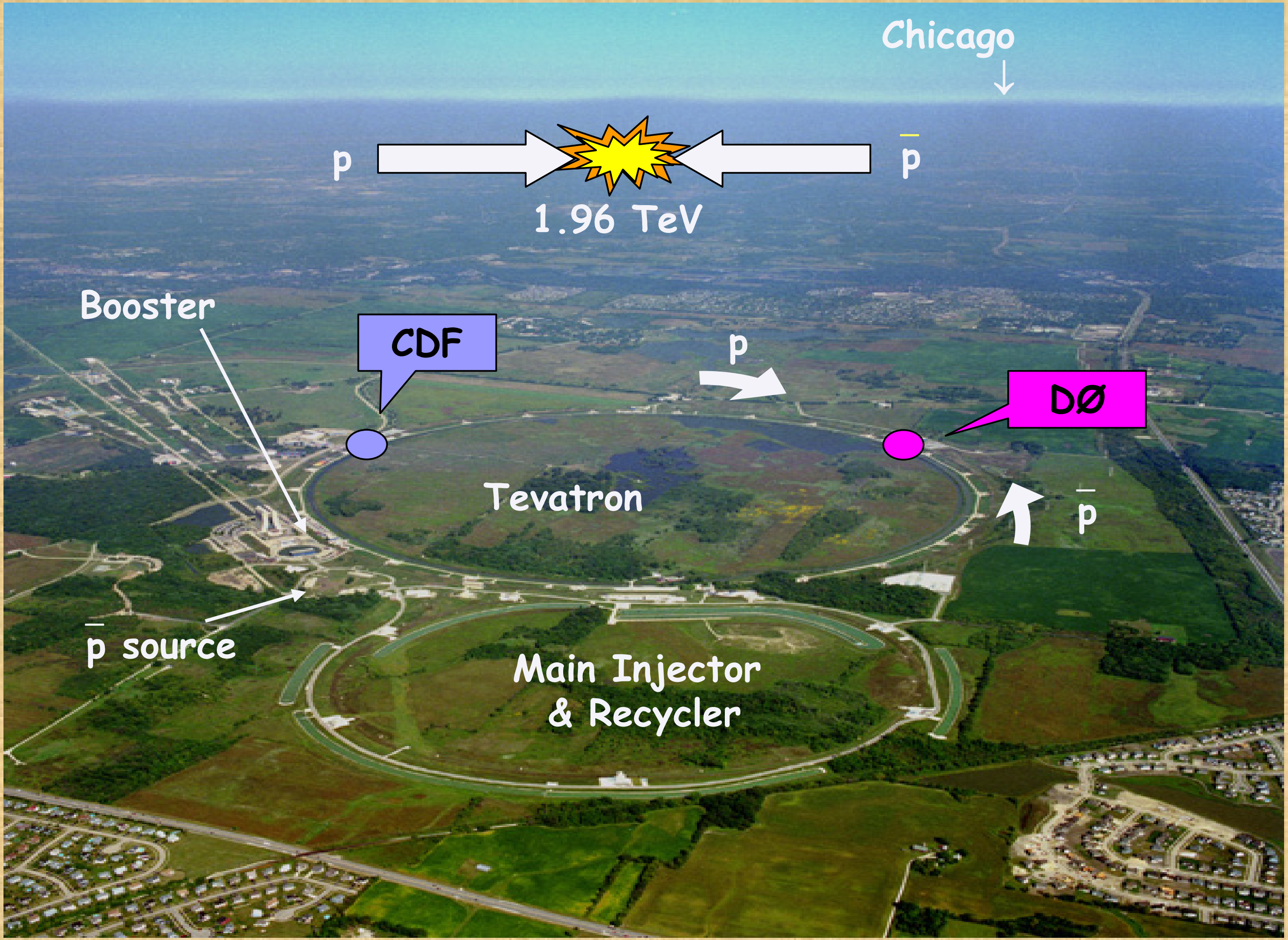
INFN/Roma

for the CDF and DØ coll.

CKM06, Nagoya

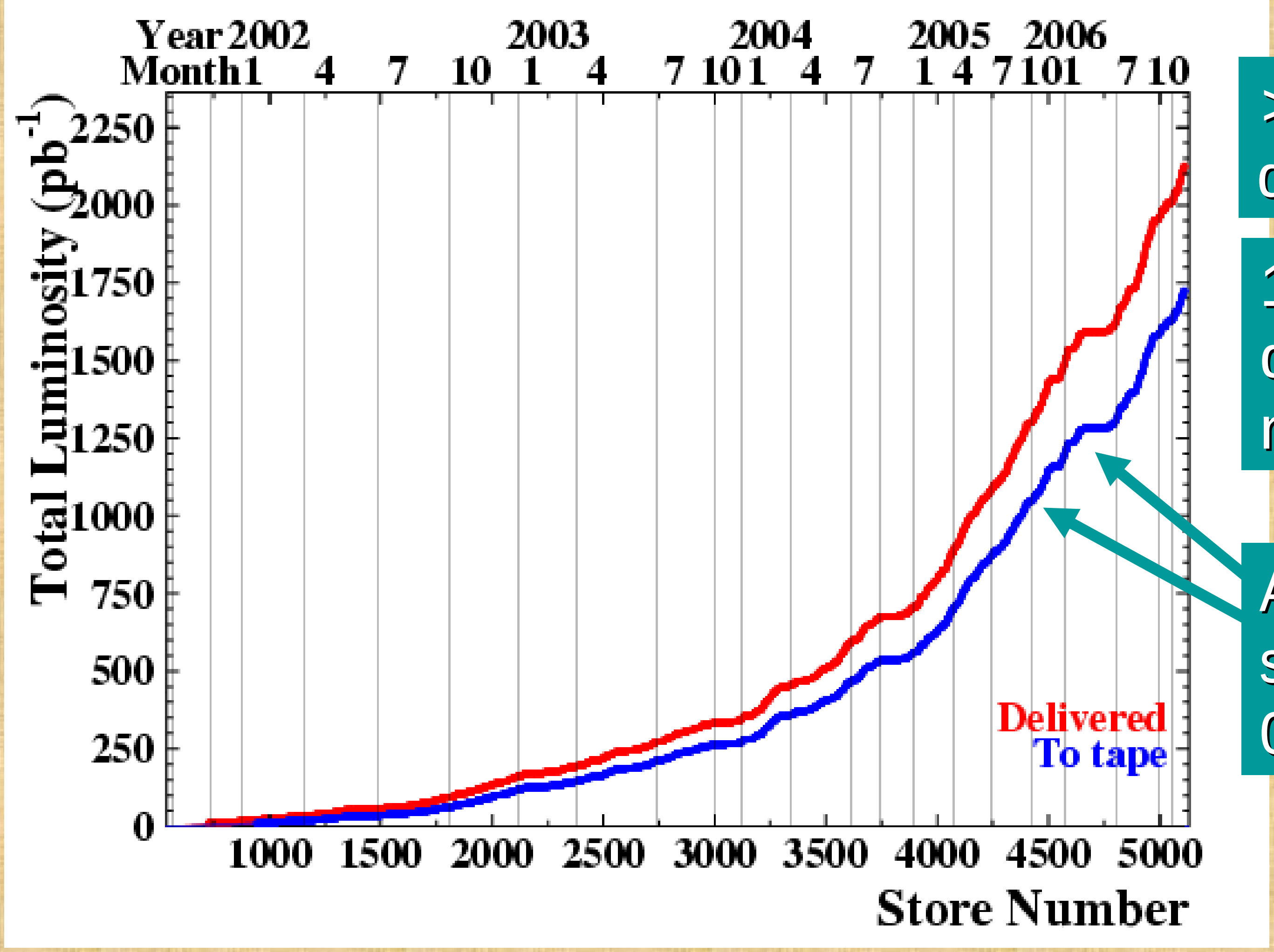
Dec 14th 2006

Tevatron



Chicago
p
$\bar{p}$
1.96 TeV
Booster
CDF
p
DØ
Tevatron
$\bar{p}$
$\bar{p}$ source
Main Injector
& Recycler

Tevatron Luminosity

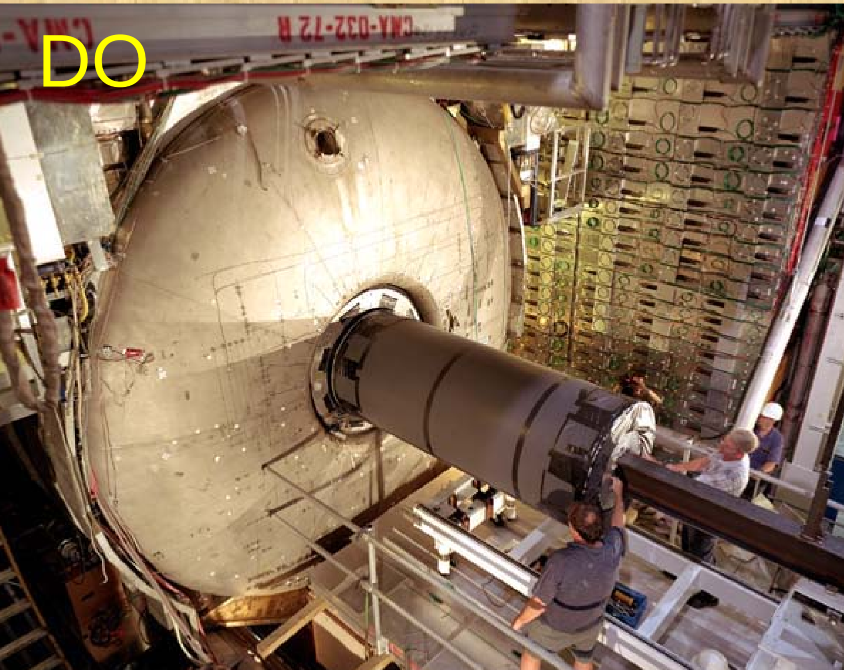


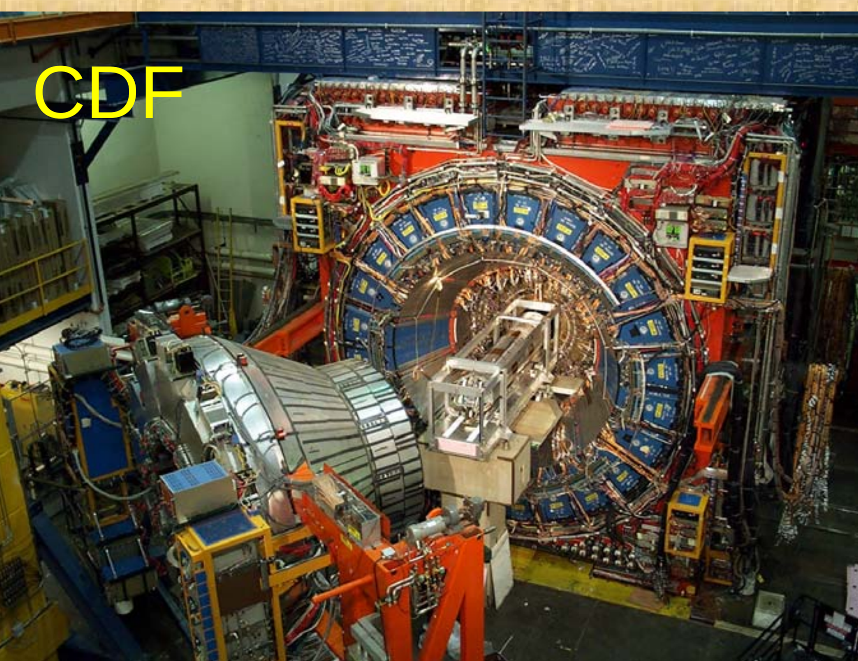
>2 fb^{-1} delivered!

1.5 fb^{-1} good data on tape now

Analysis shown today 0.7 – 1 fb^{-1}

CDF & DØ detectors

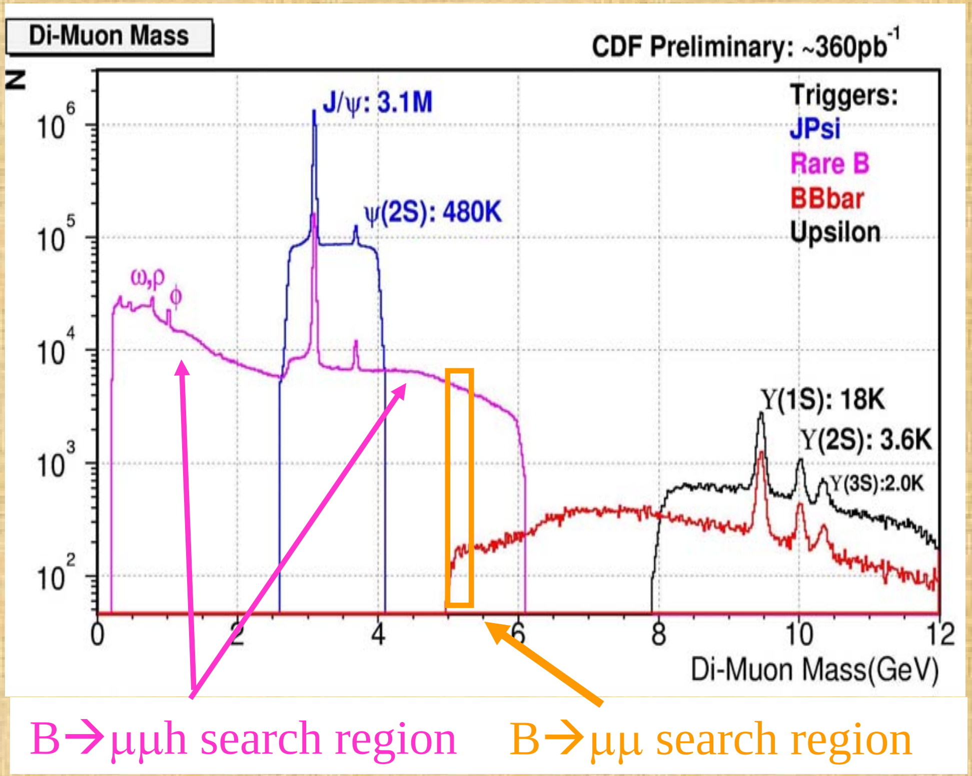




- Good muon coverage and triggering
  - DØ: $|\eta|<2.2$
  - CDF: $|\eta|<1$
- Good momentum resolution, tracking:
  - CDF: $\sigma(M_B)$~25 MeV/c2
  - reduce combinatorial and $B_d \rightarrow hh'$ → B_s search window contamination
- Good Vertexing
  - CDF: L00 (r_{inner}~1.4cm)
  - DØ: L0 upgrade (r_{inner}~1.6cm)

Triggers and Data Sample

- **CDF:**
  - di-muon triggered data
  - Two separate search channels
    - Central/central muons (CMU-CMU)
    - Central/forward muons (CMU-CMX)
  - CMU $|\eta|<0.6$, CMX $0.6 < |\eta| < 1$
  - $p_T(\mu)>1.5$ GeV/c
    - 780 pb^{-1}: $B_s(B_d) \rightarrow \mu\mu$ limit
    - 920 pb^{-1}: Search for $B_{u,d,s} \rightarrow \mu\mu h$

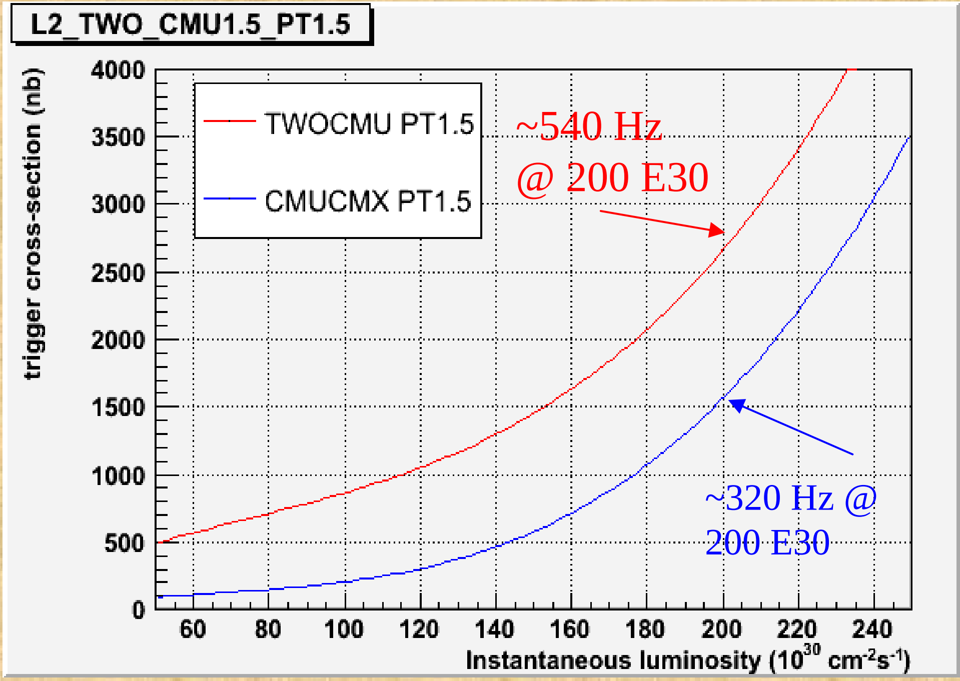


- **DØ:**
  - First 300 pb^{-1} di-muon triggered data with box opened → limit
  - 400 pb^{-1} data still blinded
  - Combined sensitivity for 700 pb^{-1} of recorded data (300 pb^{-1} + 400 pb^{-1})

S/B is expected to be extremely small. Effective bkg rejection is the key to this analysis!!

Trigger @ high lumi?

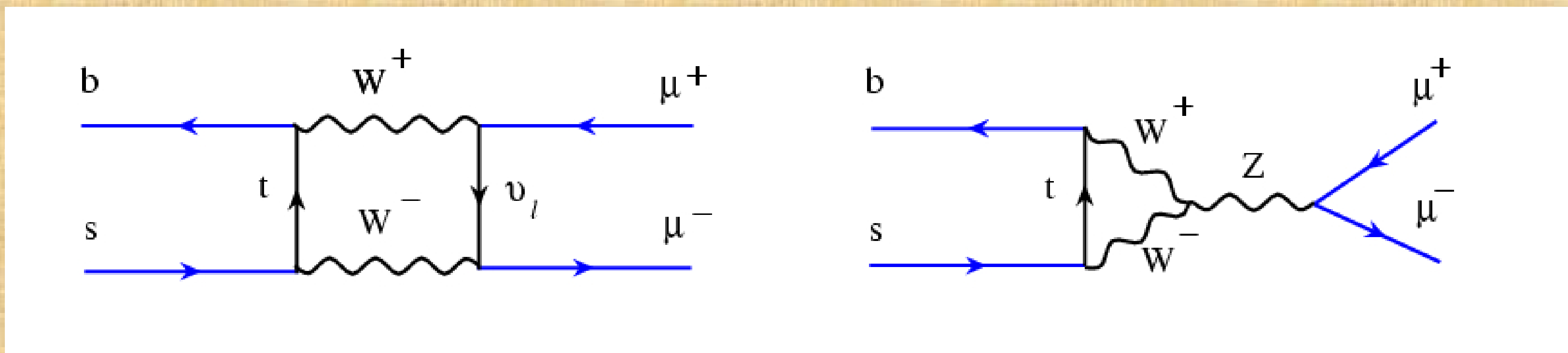
- Clever and Clever triggering as inst. Luminosity increases
- Keep high purity triggers alive at high luminosity
- Full use of available bandwidth at lower inst. Luminosity with dynamically adjusted prescales
- Hardware upgrade on the level 1 track trigger processor
  - reduce fake rate by reconstructing track segments also in the stereo layer



$B \rightarrow \mu^+\mu^-$ search at Tevatron

Motivation

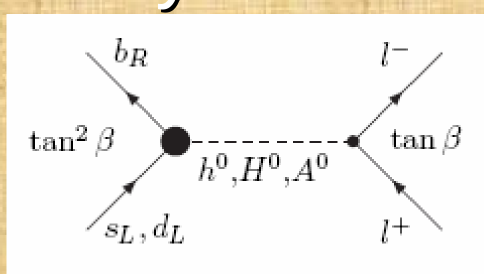
- Standard Model prediction very suppressed



$$BR(B_s \to \mu^+ \mu^-) = (3.5 \pm 0.9) \times 10^{-9}$$

(Buchalla & Buras, Misiak & Urban)

- Sizeable New Physics enhancement predicted in many scenarios, e.g. high tanβ SUSY:



Any signal @ Tevatron would be New Physics !

Strategy

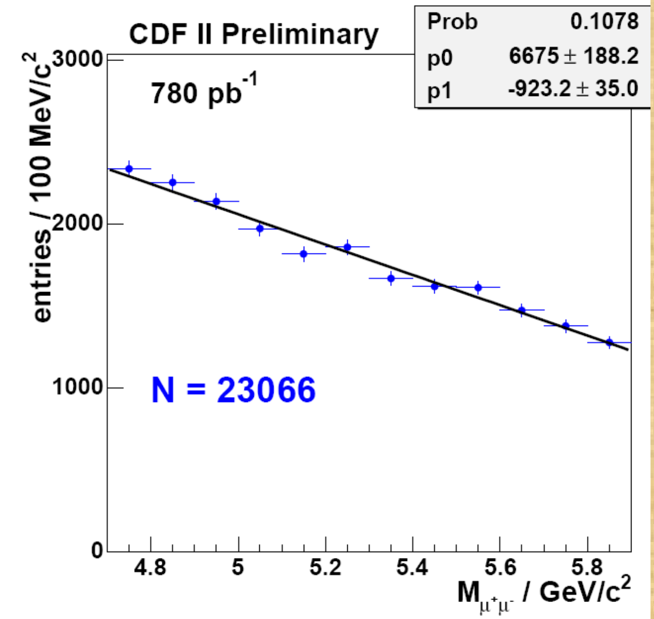
- Blind optimization using signal Monte Carlo sample and sideband data
- Normalize to known $B^+ \to J/\psi K^+$

$$BR(B_s \to \mu^+\mu^-) = \frac{N_{Bs}}{N_{B+}} \frac{\alpha_{B+} \cdot \varepsilon_{B+}^{total}}{\alpha_{Bs} \cdot \varepsilon_{Bs}^{total}} \frac{f_{b\to B+}}{f_{b\to Bs}} BR(B^+ \to J/\psi K^+) BR(J/\psi \to \mu^+\mu^-)$$

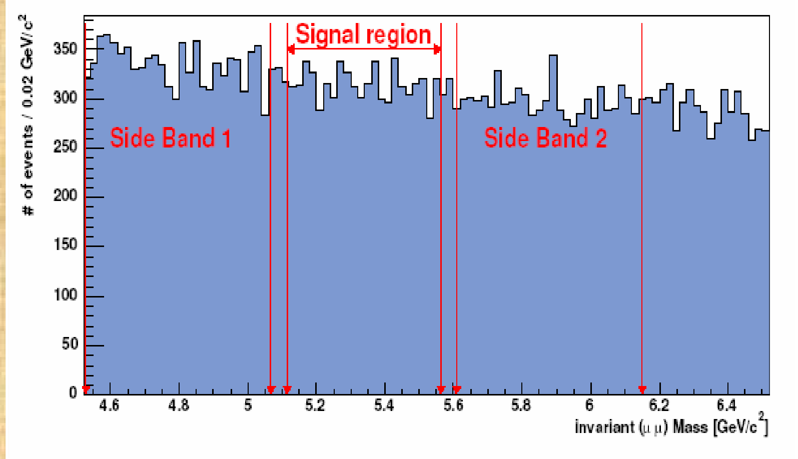
- Reconstruct Normalization mode in the same data, applying same criteria → reduce systematics
- Only ratio of efficiency matters
- Evaluate expected background and then open the box and calculate BR or limit

Preselection Cuts

- **CDF:**
  - $p_T(\mu)>2.0\ (2.2)$ GeV/c CMU (CMX)
  - $p_T(B_s$ cand.$)>4.0$ GeV/c
  - $|y(B_s)| < 1$
  - $4.669 < m_{\mu\mu} < 5.969$ GeV/c^2
  - muon quality cuts
  - good vertex
  - 3D displacement L_{3D} between primary and secondary vertex
  - $\sigma(L_{3D})<150\ \mu m$
  - proper decay length $0 < \lambda < 0.3$cm



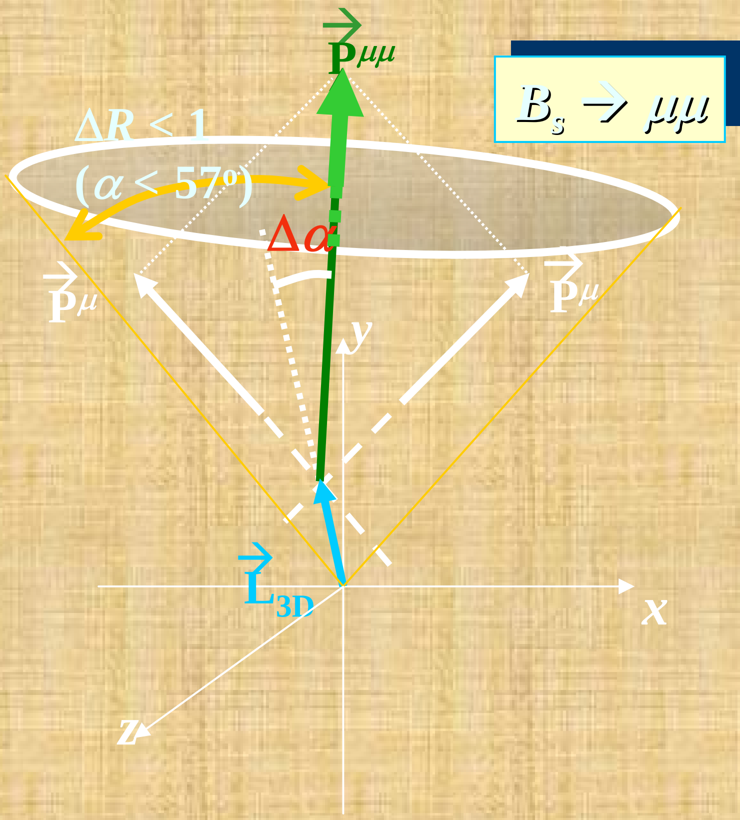
38k events after pre-selection



300 pb^{-1}

- **Pre-selection DØ:**
  - $p_T(\mu)>2.5$ GeV/c
  - $|\eta(\mu)| < 2$
  - $p_T(B_s$ cand$)>5.0$ GeV/c
  - $4.5 < m_{\mu\mu} < 7.0$ GeV/c^2
  - muon quality cuts
  - good di-muon vertex

B→μμ signal discrimination



- $\mu^+\mu^-$ mass

  ~±2.5σ mass window (60 MeV/c^2)

- B vertex displacement:

  CDF → $$\lambda = \frac{cL_{3D}M}{|\vec{p}(B)|}$$

  D0 → $$L_{xy} / \sigma_{Lxy}$$

- Isolation (Iso):

$$Iso = \frac{p_T(B)}{p_T(B) + \sum_i p_T^i(\Delta R_i < 1)}$$

(fraction of B→μμ p_T within $\Delta R = (\Delta\eta^2 + \Delta\phi^2)^{1/2} = 1$ cone)

- "pointing (Δα)":

$$\Delta\alpha = \angle(\vec{p}(B) - \vec{L}_{3D})$$

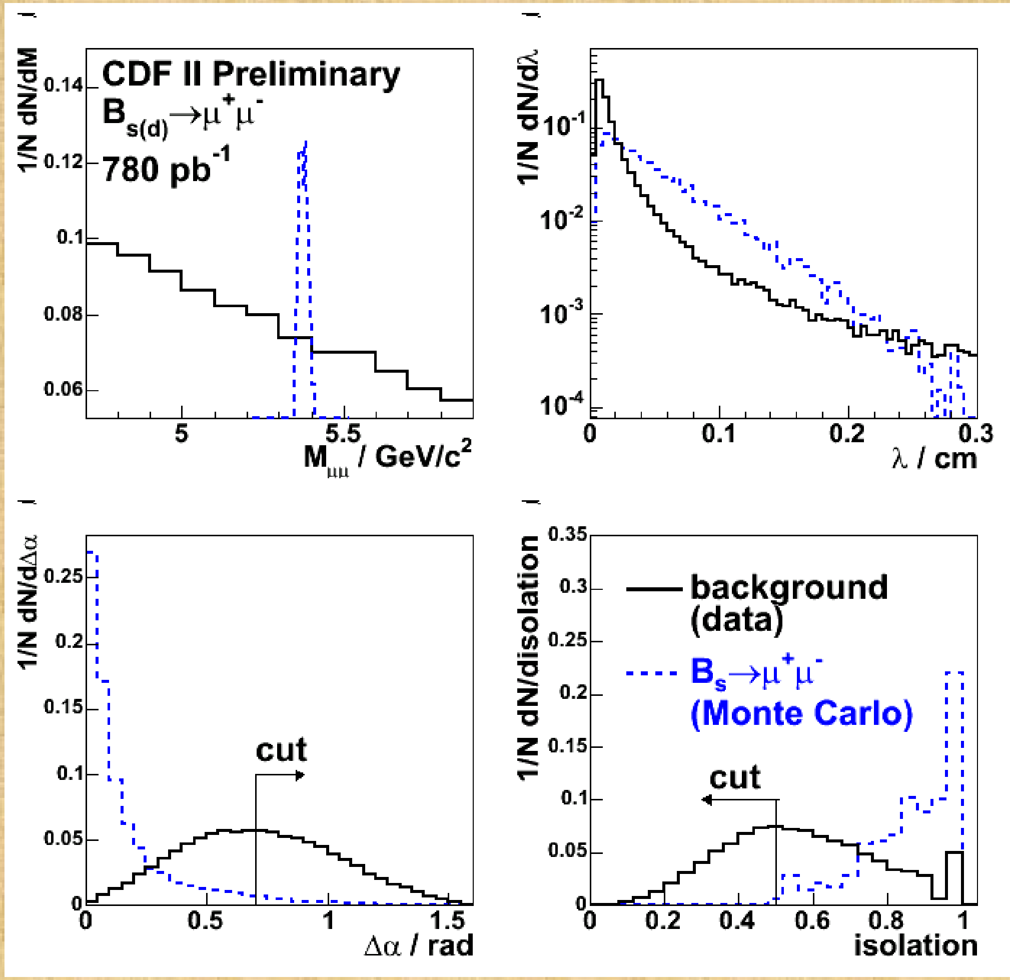
(angle between B_s momentum and decay axis)

Search Optimization @ CDF

- CDF construct a lilkelihood ratio L_R using λ, $\Delta\alpha$, Iso

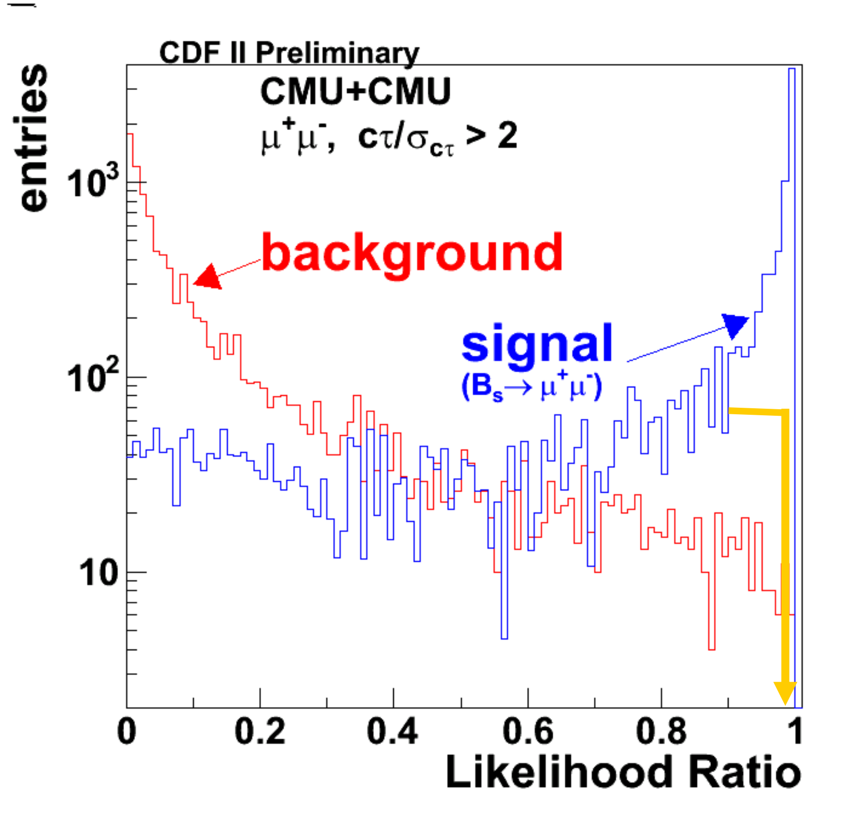
$$L_R = \frac{\prod_i P_s(x_i)}{\prod_i P_s(x_i) + \prod_i P_b(x_i)}$$

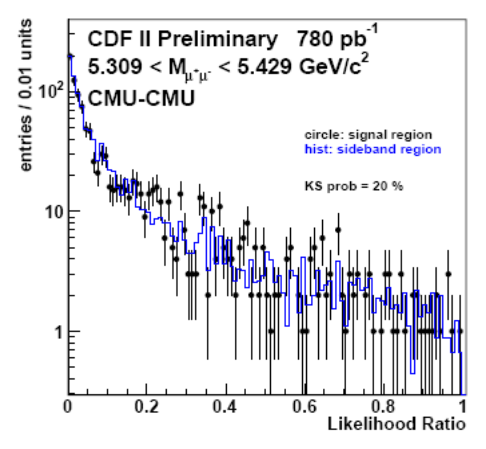
- Optimize LR cut on the expected *a-priori* 90% C.L. limit
- Background PDF from data sidebands: $4.669 < M_{\mu\mu} < 5.169$ GeV/c^2 U $5.469 < M_{\mu\mu} < 5.969$

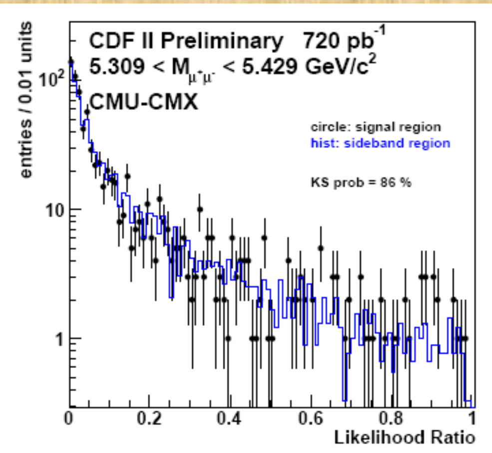


Search Optimization @ CDF

- Optimal value $L_R > 0.99$
  - Signal efficiency $\varepsilon(B_s) \cong 35\%$
  - Background Rejection $O(10^3)$

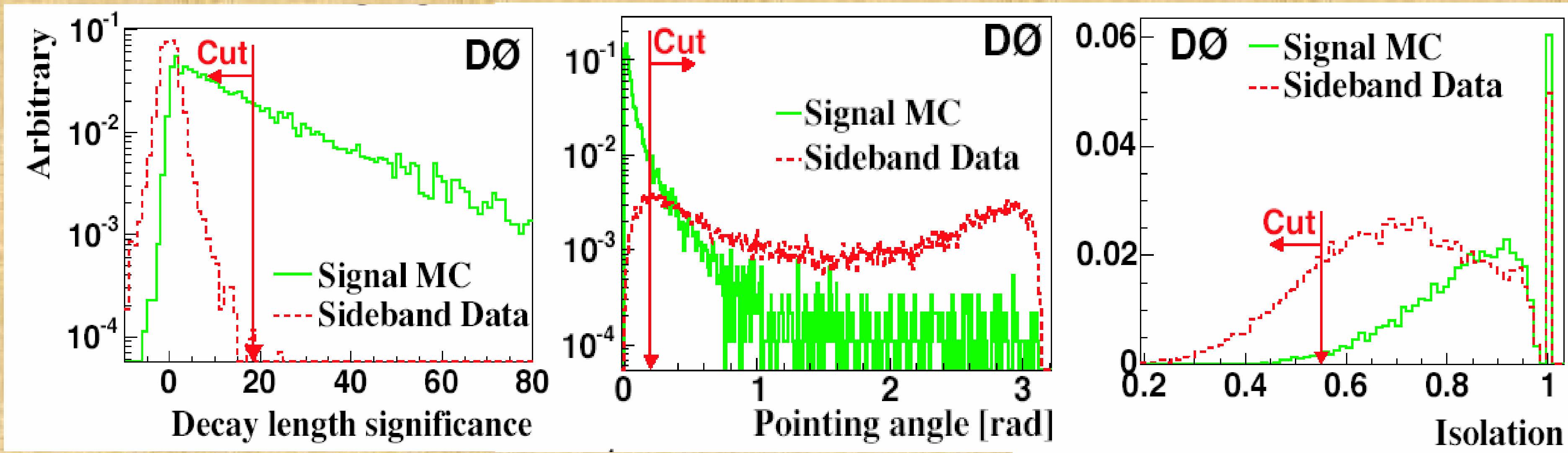






- LR distributions in signal and sidebands match
- A posteriori check…

Search optimization @ DØ

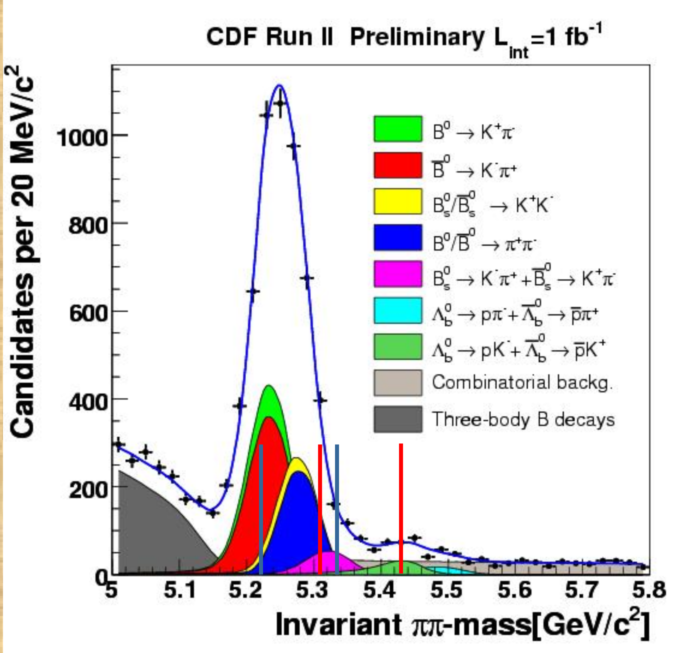


- Optimize cuts on three discriminating variables:
  - Pointing angle
  - 2D decay length significance
  - Isolation
- Maximize S/(1+sqrt(B))
- B from sidebands
- Similar efficiency and background rejection
- $\varepsilon(B_s) \cong 35\%$

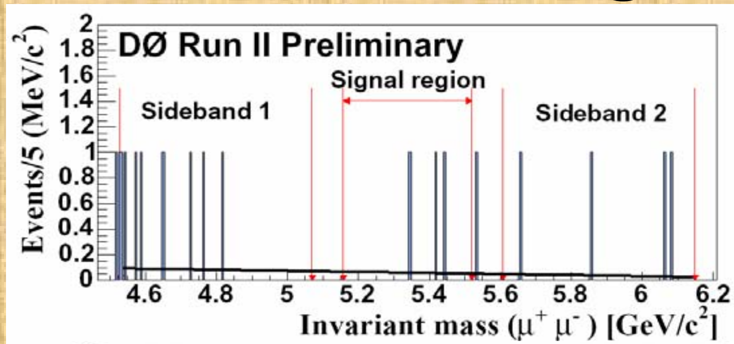
Background prediction

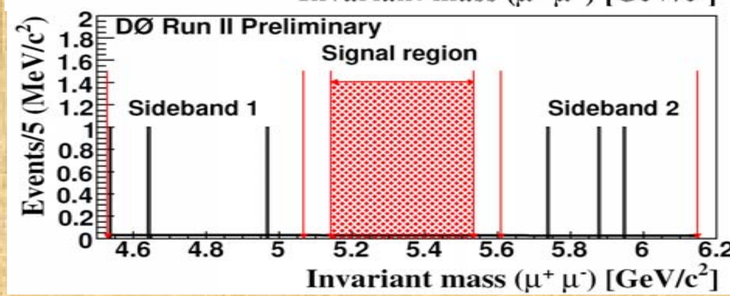
- **Combinatorics:** linear extrapolation from sidebands into ±60 MeV/c^2 signal window for CDF (± 180 @ D0)
- Cross check predictions using independent background enriched samples
  - Same Sign di-muons
  - Opposite Sign di-muons with $L_{xy}<0$
  - Fake muons
- **B→hh':** expected signal convoluted with muon fake rate (CDF)

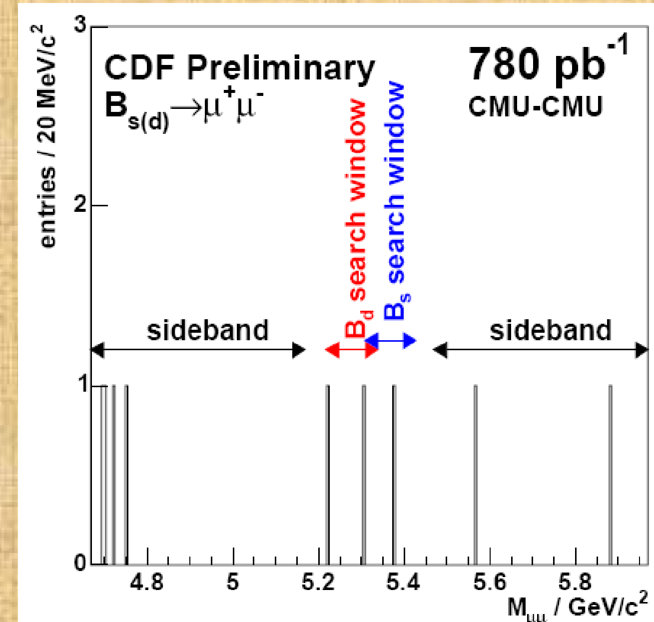
	B_s Signal Window		B_d Signal Window	
Bkg Source	CMU-CMU	CMU-CMX	CMU-CMU	CMU-CMX
Combinatoric	0.72 ± 0.29	0.36 ± 0.21	0.72 ± 0.29	0.36 ± 0.21
$B \to h^+h^-$	0.16 ± 0.06	0.03 ± 0.01	1.14 ± 0.16	0.23 ± 0.04
Total	0.88 ± 0.30	0.39 ± 0.21	1.86 ± 0.34	0.59 ± 0.21

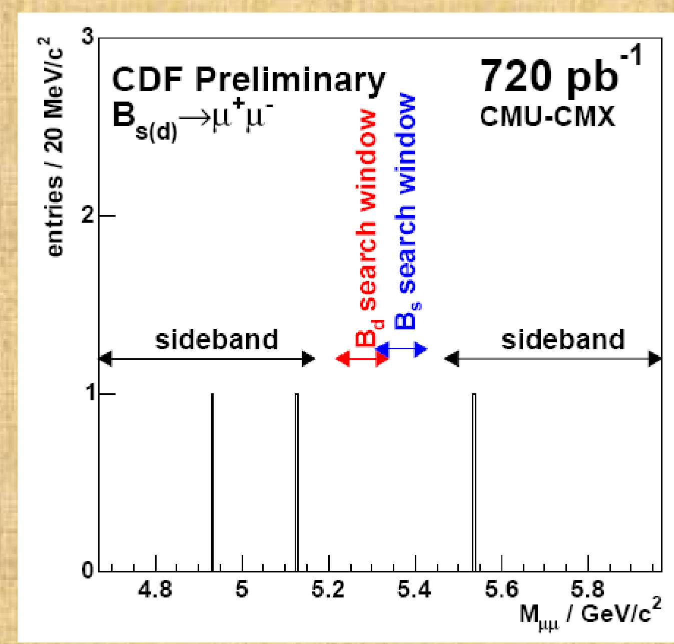


Examining Signal Boxes



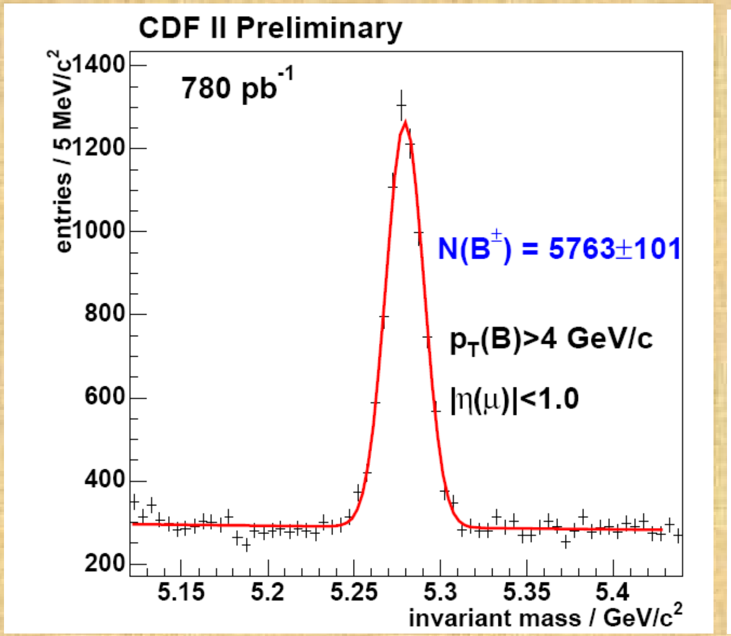


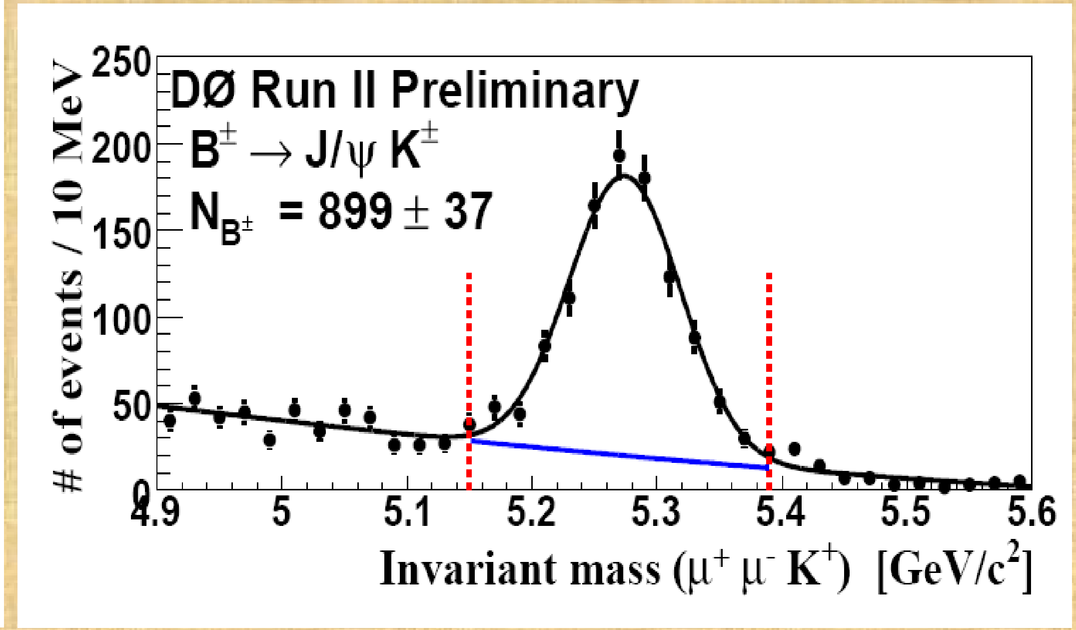




Experiment		B^0_s search		B^0_d search	
		Expected	Obs.	Expected	Obs.
CDF 780 pb^{-1}	CMU-CMU	0.88±0.30	1	1.86±0.34	2
	CMU-CMX	0.39±0.21	0	0.59±0.21	0
D0	Old Data	4.3±1.2	4		
	New Data	2.2±0.7	-		

Normalization: $B^+ \rightarrow J/\psi K^+$





- Need $B^+ \rightarrow J/\psi K^+$ yield to extract limits
- CDF (780 pb^{-1}) : 4200 (CMU-CMU) + 1550 (CMU-CMX)
- D0 (400 pb^{-1}): 900

Results

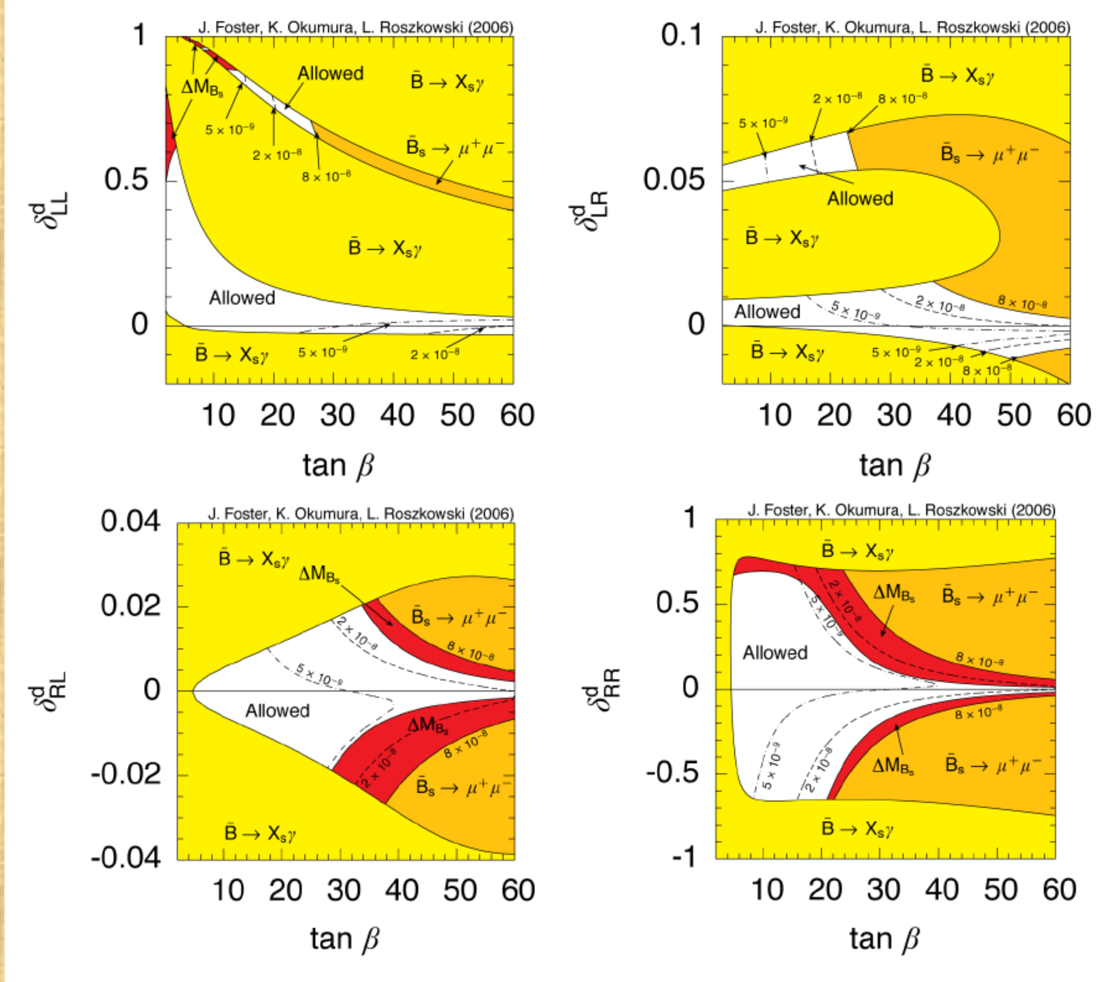
- No signal found...

- CDF B_s limit (780 pb^{-1})
  - $BR(B_s \rightarrow \mu\mu) < 8 \cdot 10^{-8}$ (10) @ 90% (95%)C.L.
- DØ average expected limit (700 pb^{-1})
  - $BR(B_s \rightarrow \mu\mu) < 19 \cdot 10^{-8}$ (23) @ 90% (95%)C.L.

- CDF B_d limit (780 pb^{-1}), world best
  - $BR(B_d \rightarrow \mu\mu) < 2.3 \cdot 10^{-8}$ (3) @ 90% (95%) C.L.
  - compare Babar (hep-ex/0408096, 110 fb^{-1})
    - $BR(B_d \rightarrow \mu\mu) < 8.3 \cdot 10^{-8}$ @ 90% C.L.

Impact on New Physics

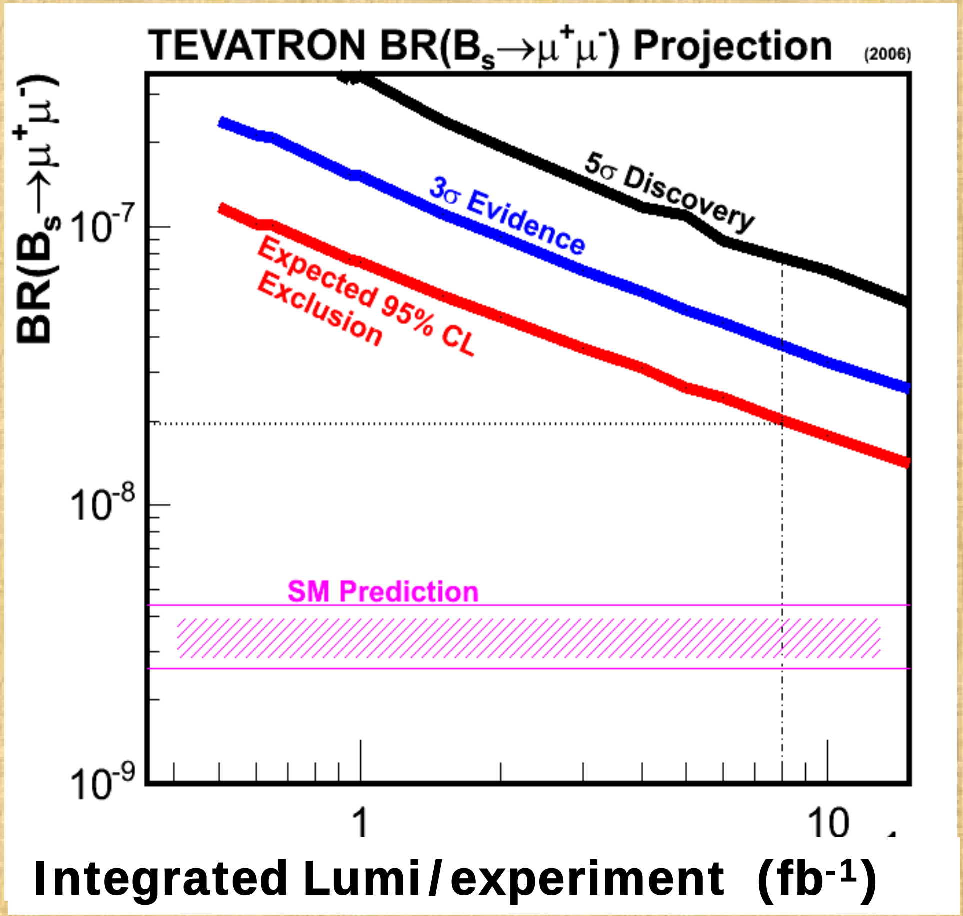
- Current constraints from Δm_s and $B_s \rightarrow \mu\mu$ are differently effective in the new physics parameter phase space
- Improved limits on $B_s \rightarrow \mu\mu$ can further constraint SUSY at large tanβ



Foster,Okumura,Roszkowski
Phys.Lett. B641 (2006) 452

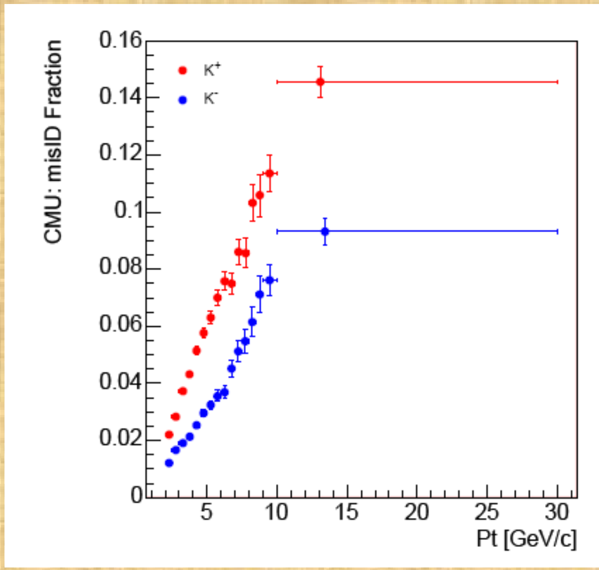
Tevatron Expected Reach

- Based on current analysis
  - might be conservative
- Can exclude region of low 10^{-8} with full Run II statistics
- Significantly improved analysis will appear soon...



Area of Improvement

- Improved muon selection based on additional information:
  - Energy deposition in the calorimeter
  - dE/dx in the drift chamber
- Significant reduction in fakes expected.
- Neural Net based final discriminant with additional background suppression power
- Use the 2-dimensional dimuon mass-discriminant plane to evaluate signal/limit
- Stay tuned for an updated results at winter conferences...



- Current muon fake rate
- Determined for Kaon and pions of each charge from high statistics $D^* \rightarrow D^0 \rightarrow K^- \pi^+$ sample

$b \rightarrow s l^+ l^-$ decays at Tevatron

Goals

- Sensitive to New Physics (Rates and Asymmetries)

- B_d and B^+ modes established at B-factories
  - $BR(B^+ \rightarrow \mu\mu K^+) = 0.34^{+0.19}_{-0.14} \times 10^{-6}$ (PDG 06)
  - $BR(B_d \rightarrow \mu\mu K^*) = 1.22^{+0.38}_{-0.32} \times 10^{-6}$ (PDG 06)

- Re-establish signals in Tevatron data and "discover" unseen $B_s \rightarrow \mu\mu\phi$ decays
  - $BR(B_s \rightarrow \mu\mu\phi) = 1.6 \times 10^{-6}$ C. Geng and C. Liu, J. Phys. G 29, 1103 (2003)

- CDF new results with 0.92 fb^{-1}
- D0 published a $BR(B_s \rightarrow \mu\mu\phi)$ limit with 0.4 fb^{-1}
  - PRD 74, 031107 (2006)

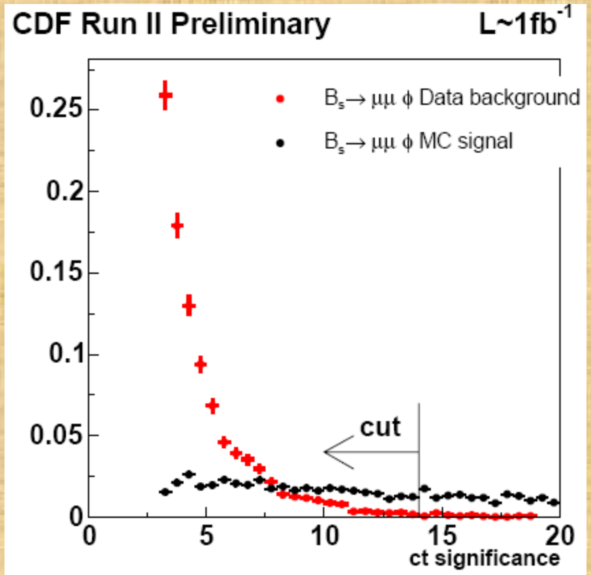
Strategy

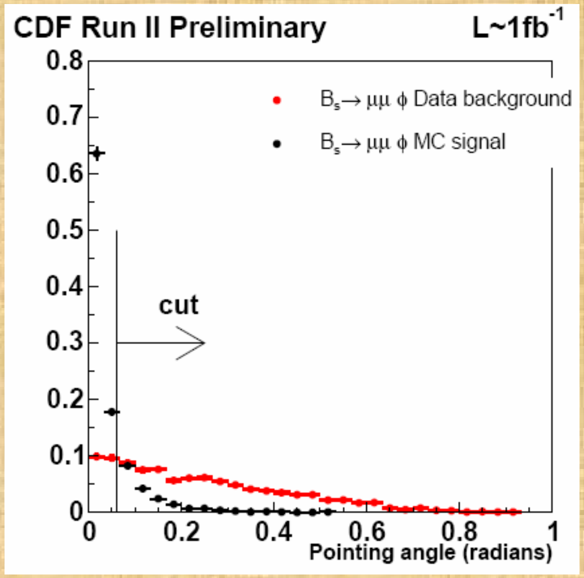
- Similar to the B→μμ case
- Normalize signal to analogous B→J/ψh (J/ψ→μμ) decays

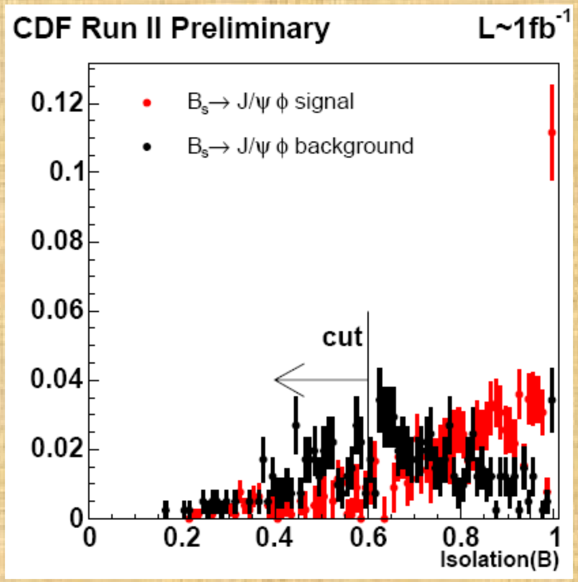
$$\frac{BR(B \to \mu^+\mu^- h)}{BR(B \to J/\psi h)} = \frac{N_{\mu\mu h}}{N_{J/\Psi h}} \frac{\varepsilon^{total}_{J/\Psi h}}{\varepsilon^{total}_{\mu\mu h}} BR(J/\psi \to \mu^+\mu^-)$$

- Blind optimization
- Exclude J/ψ and ψ' region
- Sideband data for optimization and background estimate
- Monte Carlo and data for efficiency ratios with normalization mode

Signal Selection Optimization







$$L_{XY} / \sigma(L_{XY})$$

$$|\varphi_B - \varphi_{vtx}|$$

$$Iso = \frac{p_T(B)}{p_T(B) + \sum_i p_T^i(\Delta R_i < 1.0)}$$

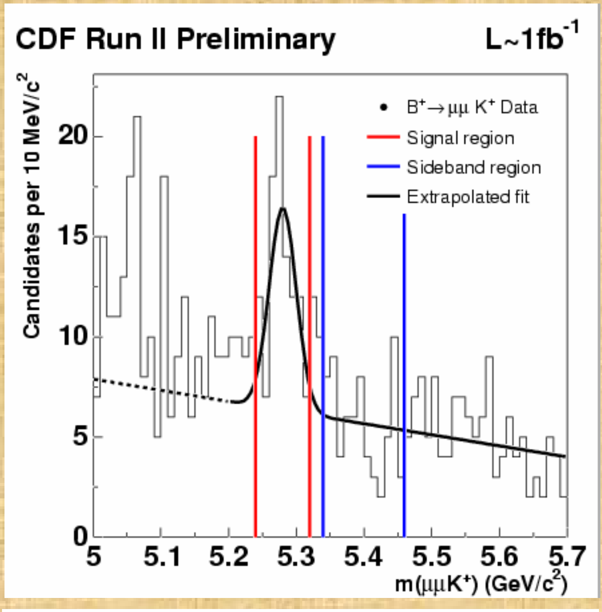
CDF/DØ similar analysis:

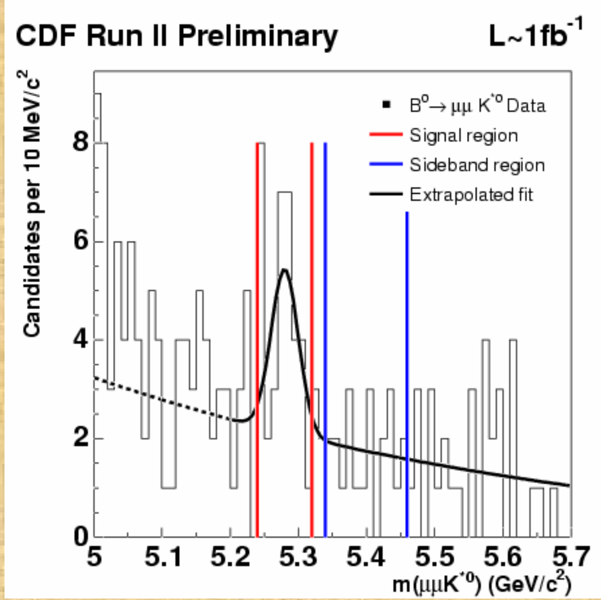
- CDF optimize Nsig / sqrt(N_{sig}+N_{bkg})
- DØ optimize Nsig / (1 + sqrt(N_{bkg}))

$B_{u,d}$ Results

- For all modes:
  - pT(B)>4.0 GeV/c
  - pT(h)>1.0 GeV/c
- $|m_{K\pi}-m_{K*}|<50$ MeV/c²
- $|m_{Kk}-m_{\phi}|<10$ MeV/c²

Mode	$B^+ \to \mu^+\mu^- K^+$	$B^0 \to \mu^+\mu^- K^{*0}$
$N_{sigwindow}$	90	35
N_{BG}	45.3± 5.8	16.5± 3.6
Gaussian Significance	4.5	2.9

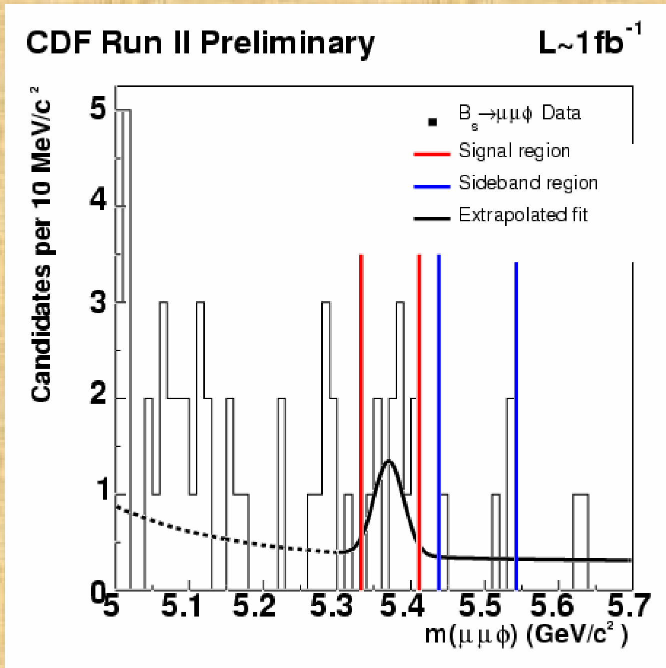




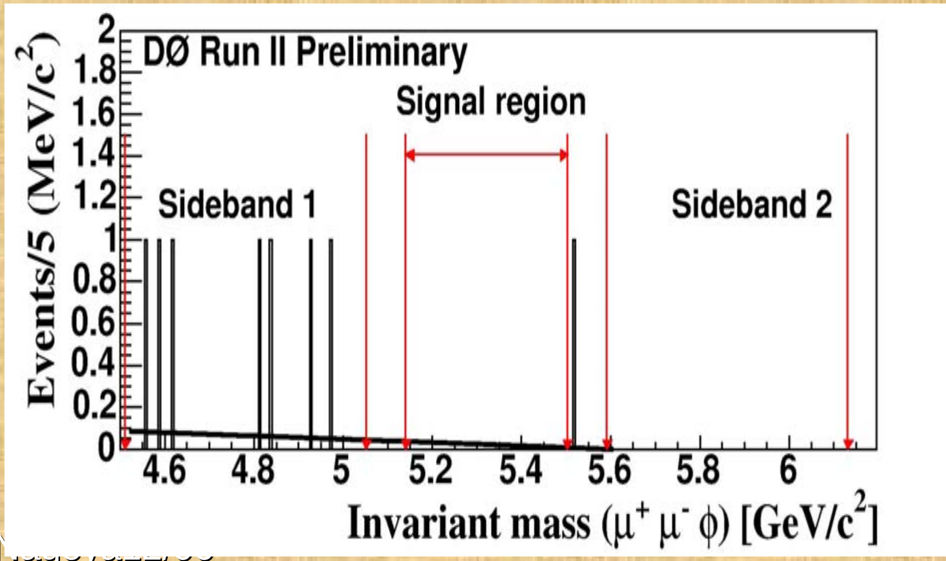
- Counting events in 2σ window around B mass, excesses seen in all modes
- Background from 3-9 σ sideband extrapolated to signal window
  - Fit shown for illustration purpose

B_s Results

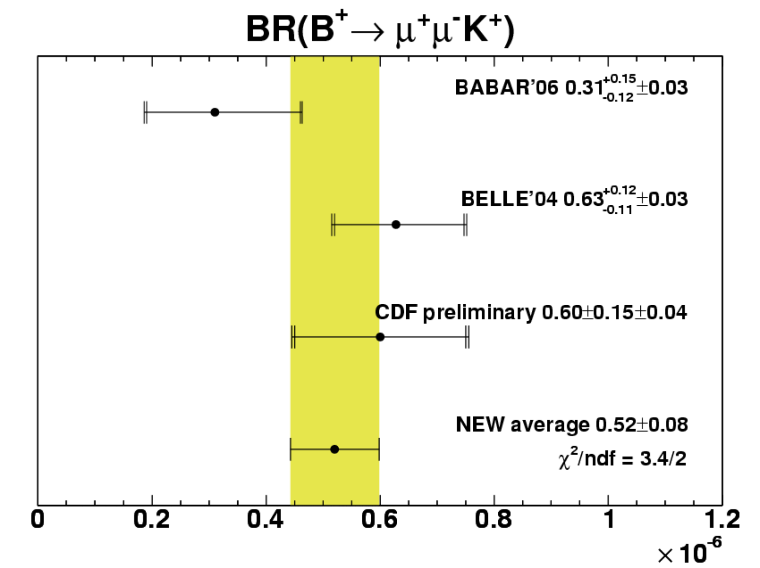
- CDF (920 pb^{-1}):
  - 11 candidates found
  - 3.5±1.5 expected background
  - 2.4 σ significance

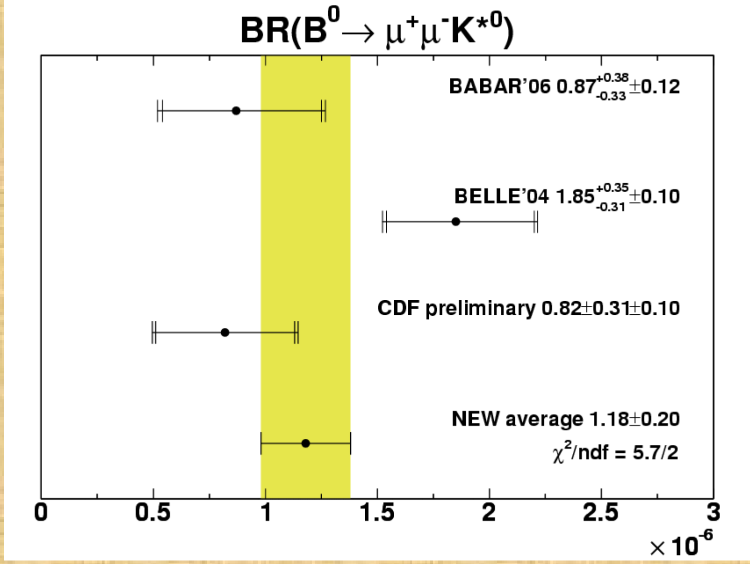


- DØ (400 pb^{-1})
  - 0 observed
  - 1.6±0.6 expected



BR ($B \to \mu\mu h$)





- Good agreement & similar uncertainty with:
  - Babar PRD 73, 092001 (2006) (208 fb^{-1} → ~10 $\mu\mu K^+$, ~15$\mu\mu K^{*0}$)
  - Belle hep-ex/0410006 (250 fb^{-1} → ~40 $\mu\mu K^+$, ~40$\mu\mu K^{*0}$)
- $BR(B^+ \to \mu\mu K^+) = [0.72 \pm 0.15(stat.) \pm 0.05(sys.)]\times10^{-6}$ (45 ev.)
- $BR(B^0 \to \mu\mu K^*) = [0.82 \pm 0.31(stat.) \pm 0.10(sys.)]\times10^{-6}$ (20 ev.)

- $BR(B_s \to \mu\mu\phi) < 2.4 \times10^{-6}$ @ 90% C.L.

  $= [1.16 \pm 0.56(stat.) \pm 0.42(sys.)]\times10^{-6}$
  - Improve upon DØ limit (400 pb^{-1}) $BR(B_s \to \mu\mu\phi) < 3.3 \times 10^{-6}$ @ 90% C.L.

Summary

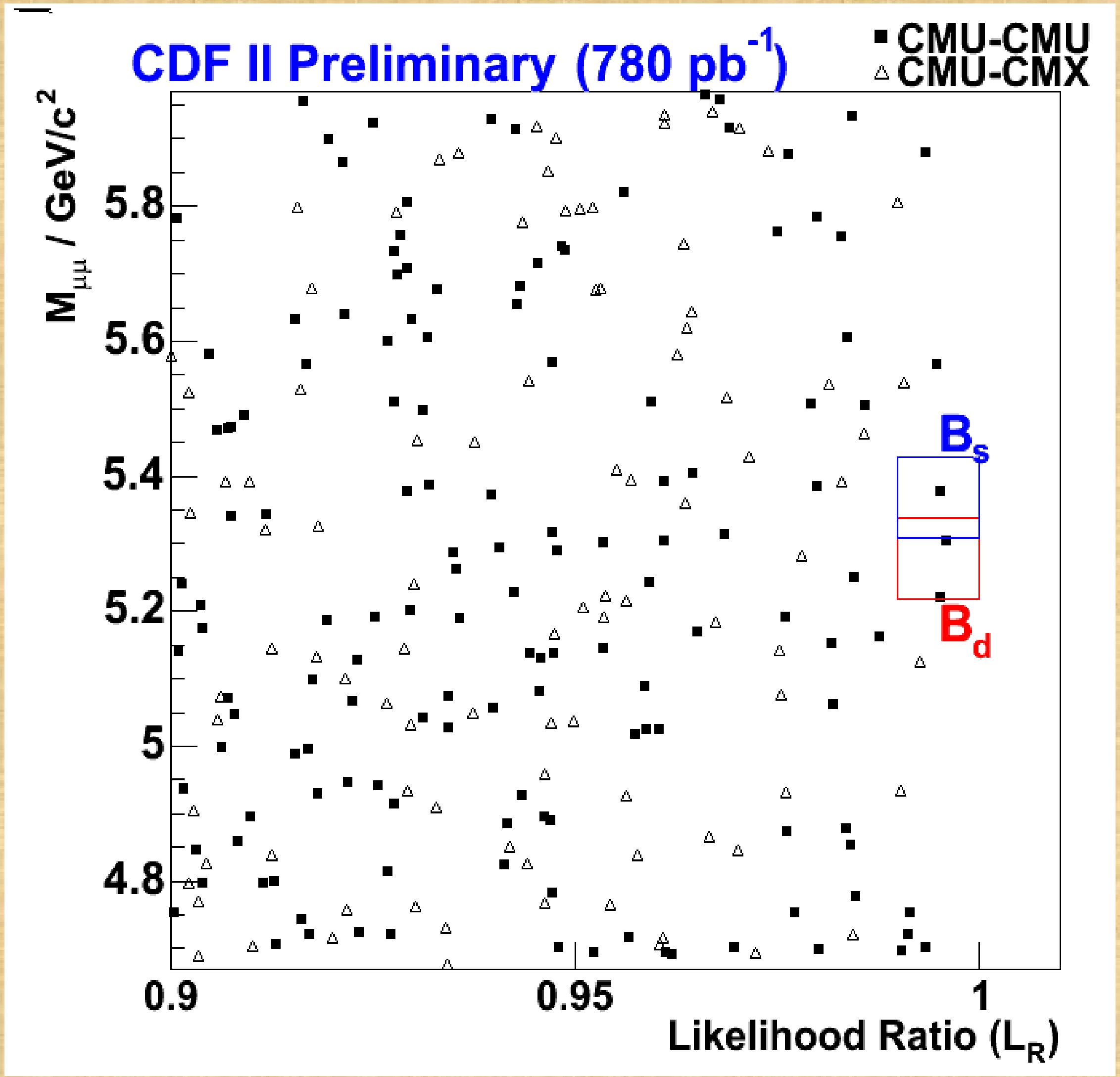
- CDF/DØ analyzed ~800 pb^{-1} of Run II data searching for $B \rightarrow \mu\mu$ signal:
  - Current limits in the 10^{-8} territory
  - No major obstacle in pushing down limits with increasing exposure
  - Significantly improved analysis with >1 fb^{-1} data sample
- Constraining more & more New Physics...

- CDF/DØ entering the $b \rightarrow sll$ arena:
  - New solid $B^+ \rightarrow \mu\mu K$ signal from CDF
  - A 2.4 σ excess in the $B_s \rightarrow \mu\mu\phi$ reported from CDF
    - U.L. limit close to SM prediction

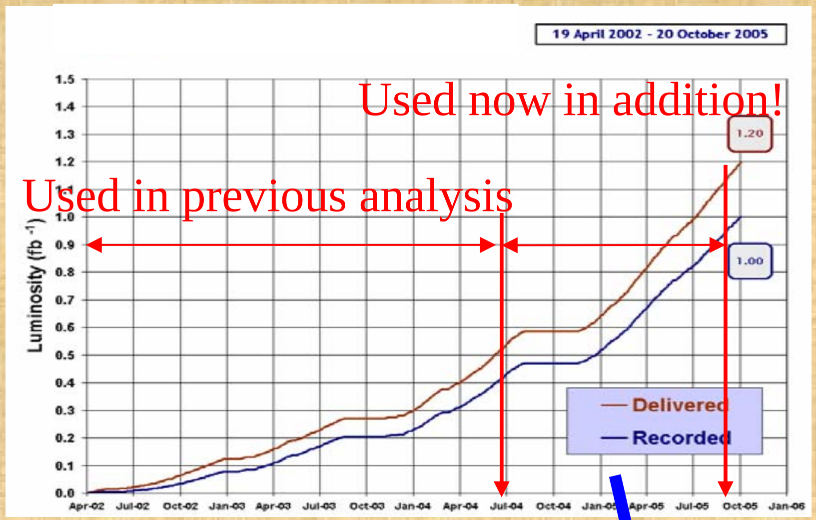
- 1.5 fb^{-1} on tape: more to come...

BACKUP

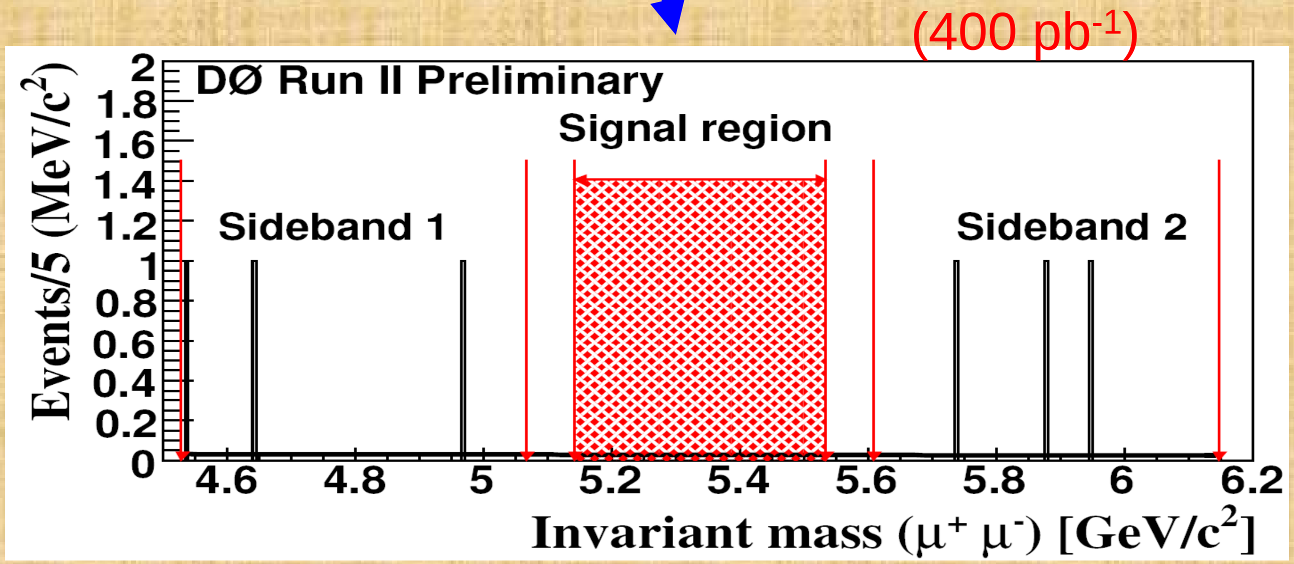
MB vs Likelihood Ratio



D0 SENSITIVITY FOR 700 pb^{-1}



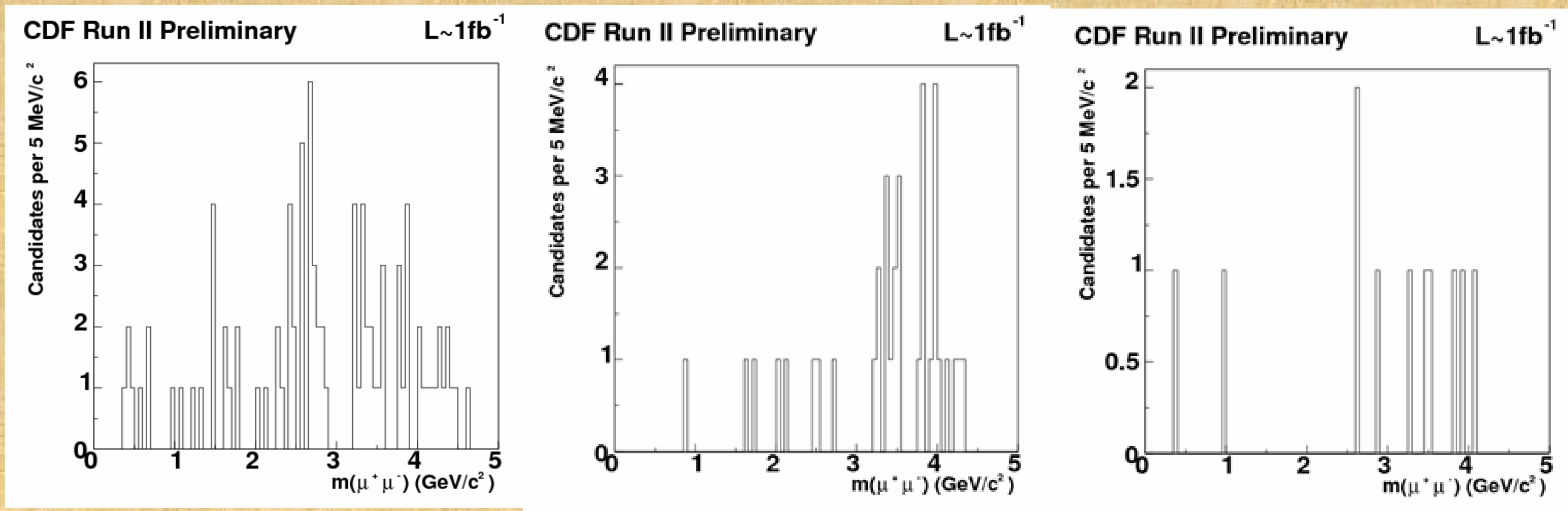
- Obtain a sensitivity (w/o unblinding) w/o changing the analysis
- Combine "old" Limit with obtained sensitivity



Cut Values changed only slightly!

Expect 2.2 ± 0.7 background events

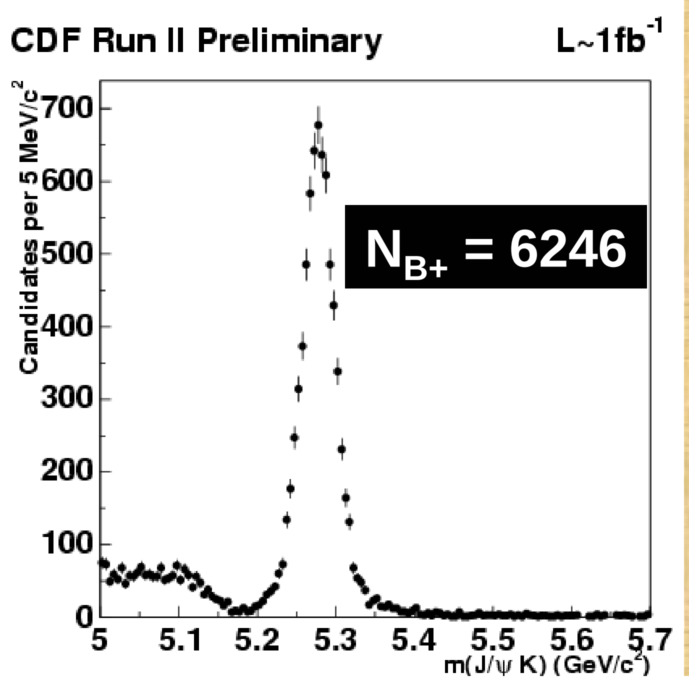
Signal $m_{\mu\mu}$ Spectra

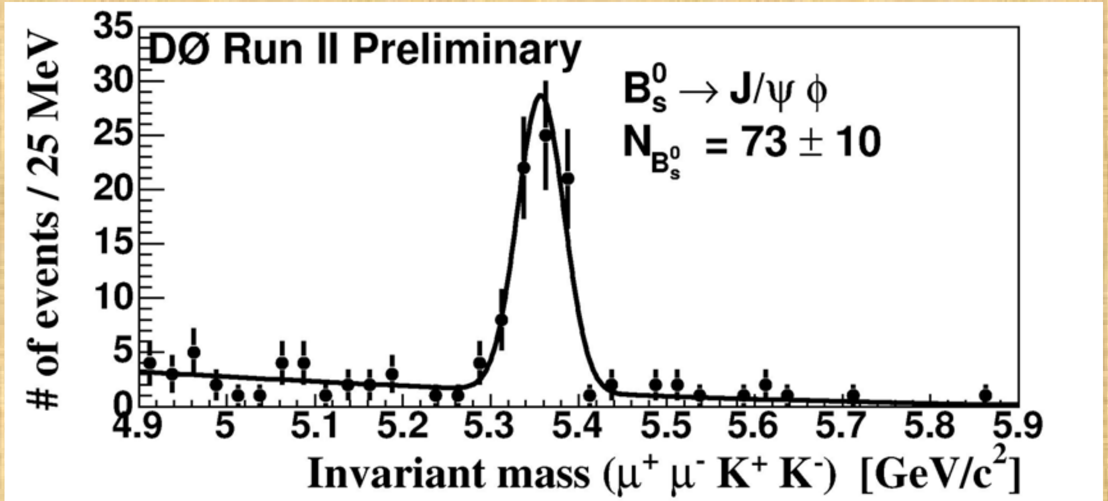


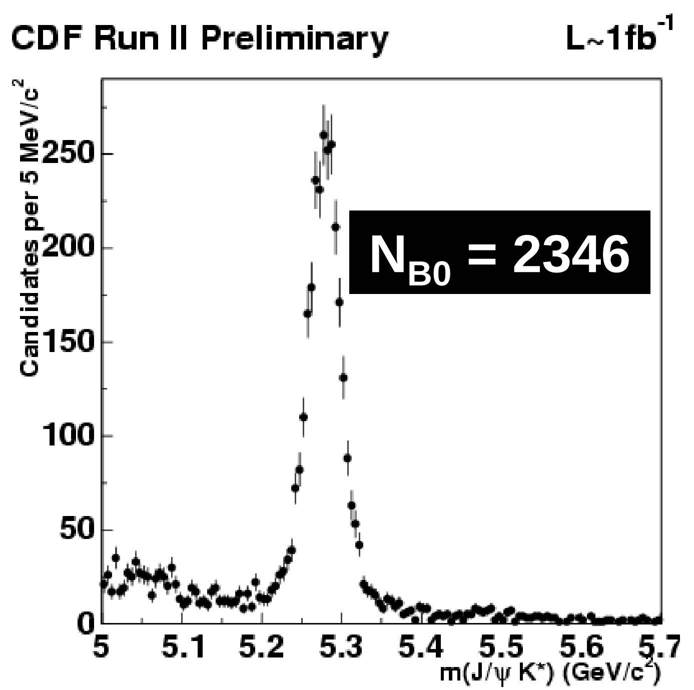
- Mass spectra not corrected for efficiency/background
- Resonance veto:
  - $2.9<m_{\mu\mu}<3.2$ (J/ψ)
  - $3.6<m_{\mu\mu}<3.75$ (ψ')
  - D (D+,Ds) any 2(3) track combination within 25 MeV of PDG mass

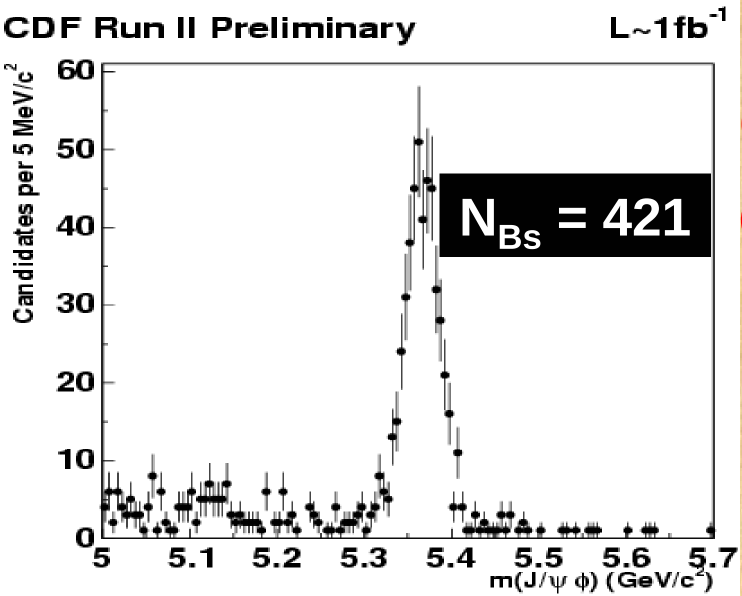
NORMALIZATION MODES

Apply similar pre-selection requirements as B→μμ analysis









Clean samples of norm events

CDF trigger architecture

- Crossing: 396 ns: 2.5 MHz
- Level 1: hardware
  - Calorimeter, Muon, Tracks
  - 30kHz (reduction ~x100)
- Level 2: hardware + CPU
  - Cal cluster, Silicon tracks
  - 900 Hz (reduction ~x60)
- Level 3: Linux PC farm
  - ~ Offline quantities
  - 100 Hz (reduction ~ x5)