Current Experimental Results on Purely Leptonic B and D Decays

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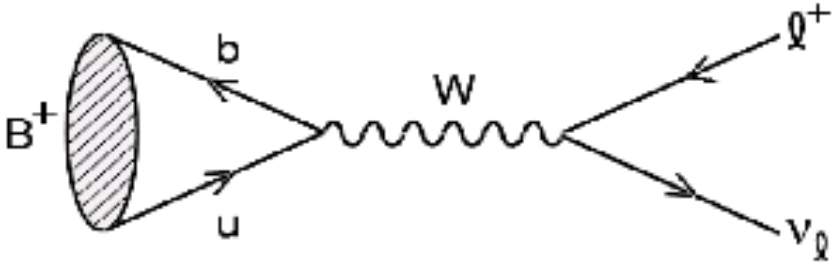
Outline

- Charged current decays:
  - $B^+ \rightarrow \tau^+\nu$ (Belle)
  - $B^+ \rightarrow \mu^+\nu$ (BaBar)
  - I won't cover $D_s \rightarrow \tau\nu$ decays (see …)
- Neutral current decays (all are flavor changing):
  - $B^0_{d,s} \rightarrow \mu\mu$ (DØ)
  - $B^0_{d,s} \rightarrow ee$ (CDF)
  - $D^0 \rightarrow \mu\mu$ (CDF)
- Lepton flavor violating decays:
  - $B^0_{d,s} \rightarrow e\mu$ (CDF)
- Summary

Charged Current Decays

Tree-level W annihilation decay:



BF helicity suppressed and related to f_B and $|V_{ub}|$:

$$\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B}{8\pi} m_\ell^2 (1 - \frac{m_\ell^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$

Charged Higgs can enhance or suppress BF:

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H$$

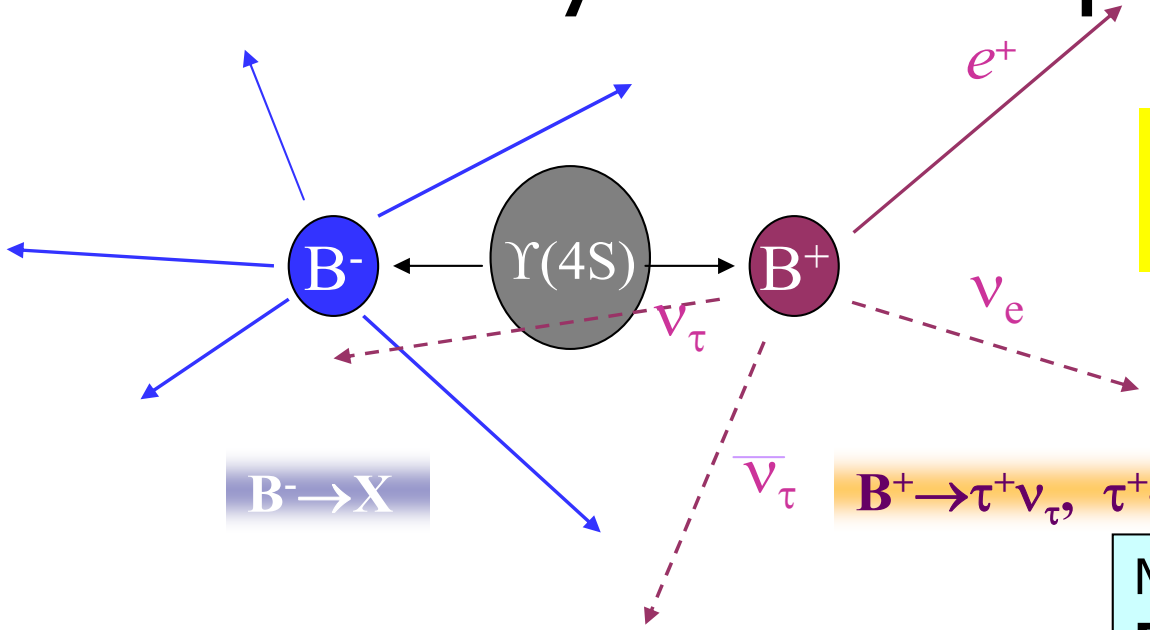
$$r_H = (1 - \frac{m_B^2}{m_H^2} \tan^2\beta)^2$$

W-S Hou, Phys. Rev. D48, 2342 (1993).

Unparticle physics may produce CP violation:

R. Zwicky, arXiv:0707.0677

B→τν Analysis Concepts at B Factory

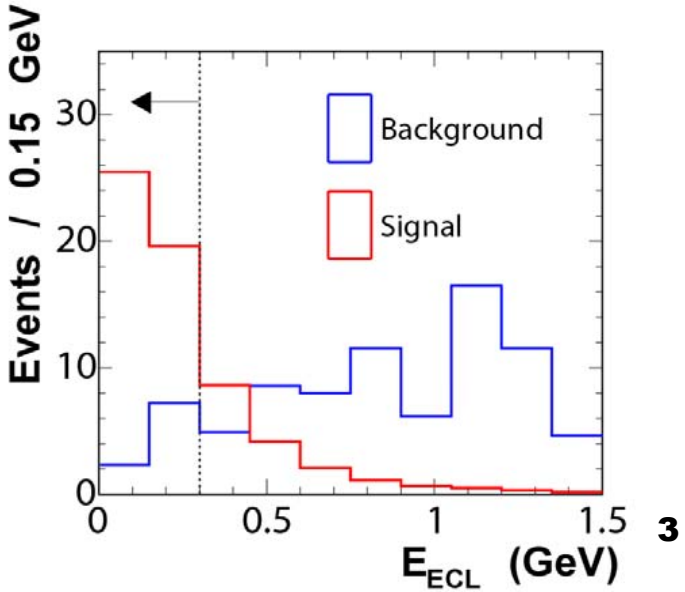


More than 2 neutrinos appear in B →τν decay

Most powerful discriminant variable:
Extra calorimeter energy E_{ECL}

- Require **no** particle remain after removing products of tagging B and the particle(s) from B→τν decay

Tagging side :
Semileptonic or Hadronic B Decay
Signal side :
Detect τ daughter particle(s)



BELLE $B \rightarrow \tau\nu$ Analysis

Earlier BELLE analysis used fully hadronic tag decays and had a 3.5 σ signal with 449 × 10^6 BB pairs.

PRL 97, 251802 (2006).

BABAR used both hadronic and semileptonic tag decays and had a 2.6 σ signal with 383 ×10^6 BB pairs.

PRD 77, 011107(R) (2008), PRD 76, 052002 (2007).

New BELLE analysis uses semileptonic tag decays with 1 prong τ decays and 657 × 10^6 BB pairs.

Kinematic discriminant for tag decay:

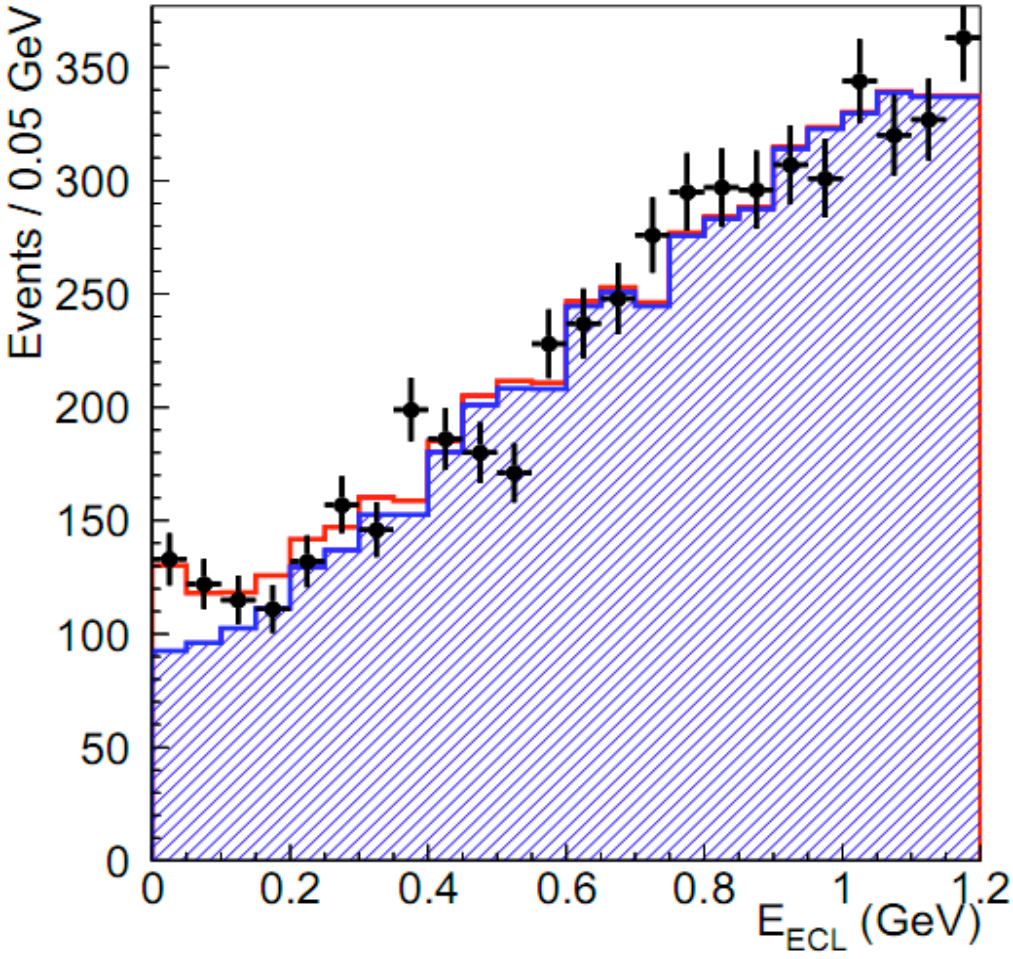
$$\cos\theta_{BDl} = \frac{2E_B E_{Dl} - M_B^2 - M_{Dl}^2}{2P_B P_{Dl}}$$

BELLE $B \rightarrow \tau\nu$ Analysis

Use Extra Calor. Energy to identify signal.

Find 154 $B \rightarrow \tau\nu$ decays with 3.8 σ significance.

Yields new semileptonic-tagged B.F. of:



$$\left[1.65^{+0.38}_{-0.37}(stat)^{+0.35}_{-0.37}(syst)\right] \times 10^{-4}$$

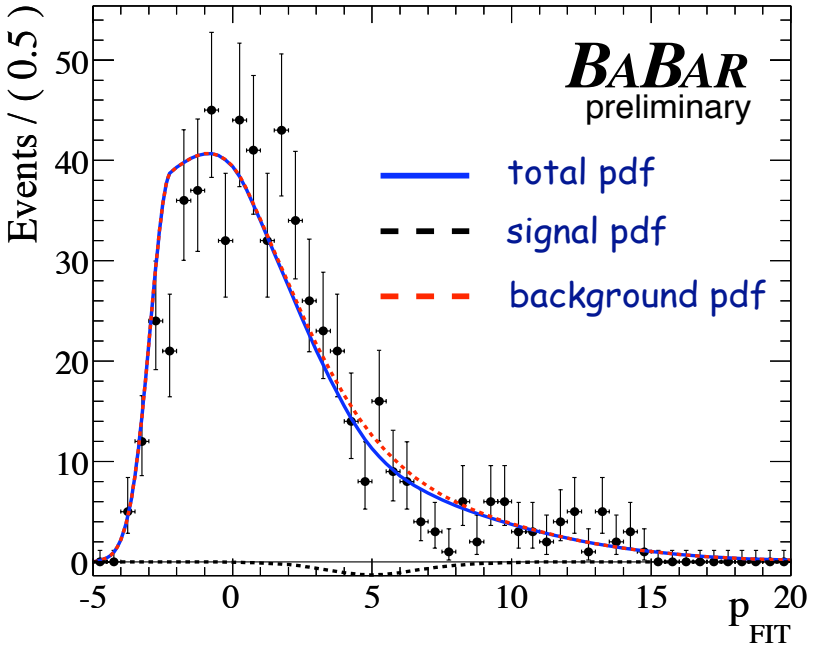
$B^{\pm} \to \mu^{\pm} \nu$ inclusive result

* Candidate lepton momentum very discriminating, both in B rest frame (p_{REST}) and in CM frame (p_{CM})

* Signal and background yields extracted from a Fisher discriminant distribution built up from p_{CM} and p_{REST}

$$p_{FIT} = a_1 + a_2 \cdot p_{CM} + a_3 \cdot p_{Rest}$$

$$a_1 = -60.5203,\ a_2 = 6.6544 \text{ and } a_3 = 18.272.$$



source	Value ± Tot. Error
N_{bb}	4.47e+08 ± 1.1%
signal efficiency	0.0464 ± 0.00191
signal yield	-11.9 ± 20.3

UL @ 90% CL in Bayesian approach

BR($B^+ \to \mu^+ \nu$) < 1.3 x 10^{-6}

With full dataset ~420 fb^{-1}

Summary of B → τν and μν Results

Average hadronic and semilep. tag results from BELLE

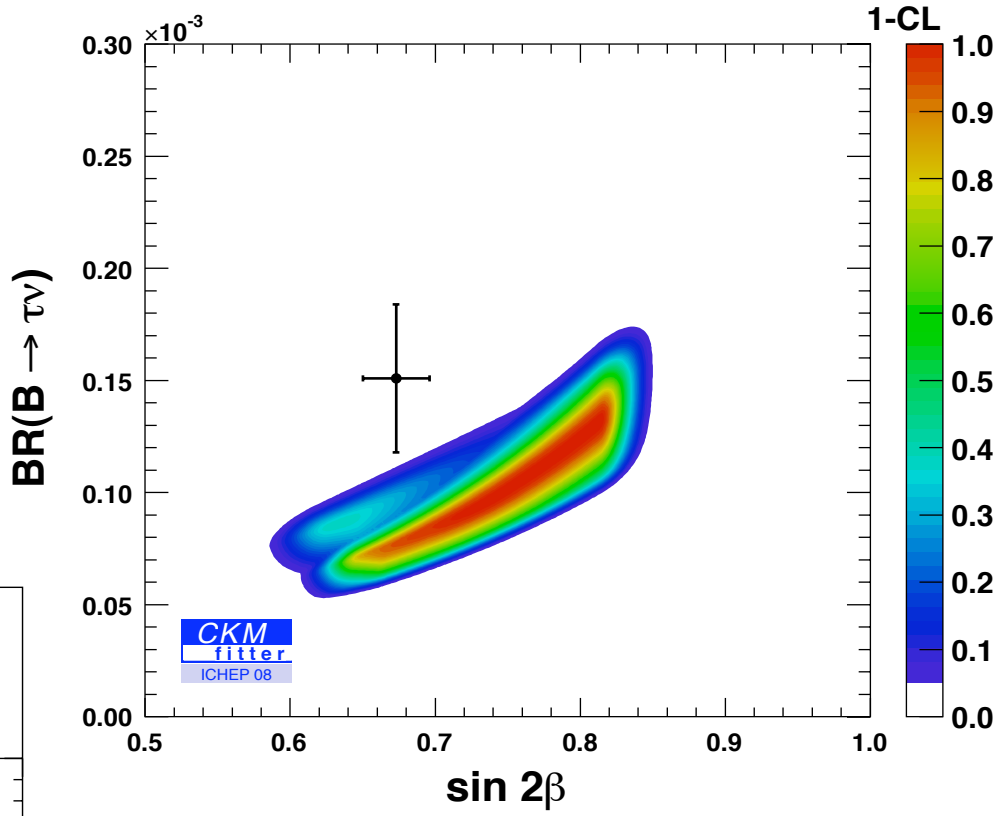
hadronic: $\left[1.79^{+0.56}_{-0.49}(stat)^{+0.46}_{-0.51}(syst)\right] \times 10^{-4}$

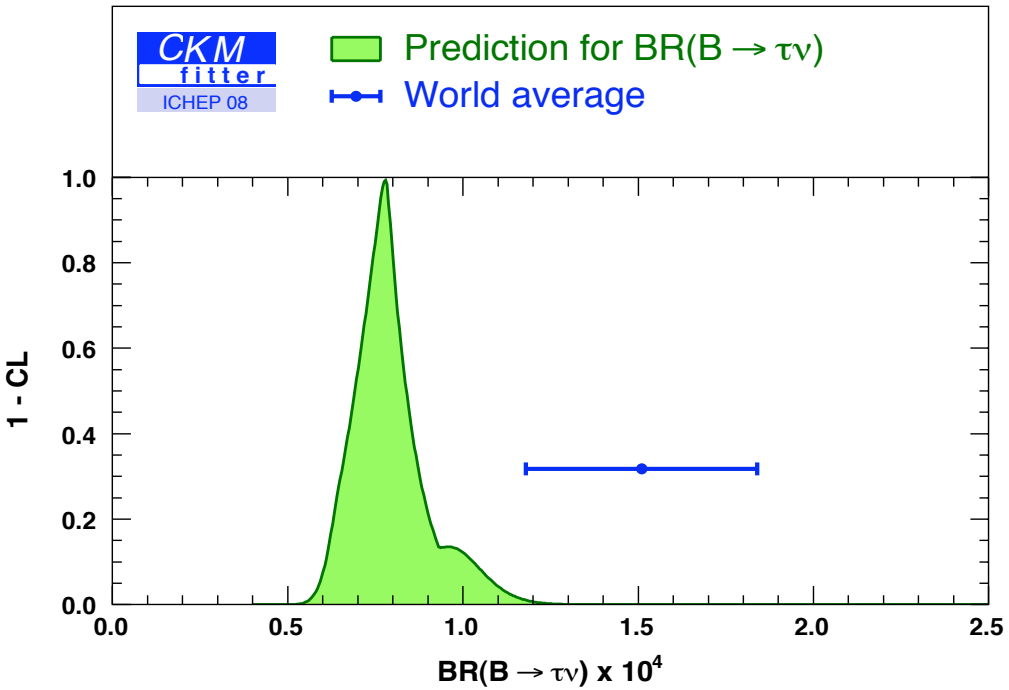
semilep.: $\left[1.65^{+0.38}_{-0.37}(stat)^{+0.35}_{-0.37}(syst)\right] \times 10^{-4}$

	$B^+ \to \tau^+\nu$	$B^+ \to \mu^+\nu$
PDG 2008	$(1.4 \pm 0.4) \times 10^{-4}$	(90% C.L. limits)
BaBar	$(1.20 \pm 0.40 \pm 0.36) \times 10^{-4}$	$\leq 1.3 \times 10^{-6}$
BELLE	$(1.70 \pm 0.42) \times 10^{-4}$	$\leq 1.7 \times 10^{-6}$
New Avg. (HFAG)	$(1.51 \pm 0.33) \times 10^{-4}$	

CKM Fitter and B → τν Results

The new B.F. average is a bit higher than preferred by a global fit to CKM quantities.





Can provide H^+ mass constraint.

FCNC Decays: Sensitive to NP

FCNC decays forbidden at tree level, and proceed through loop diagrams.

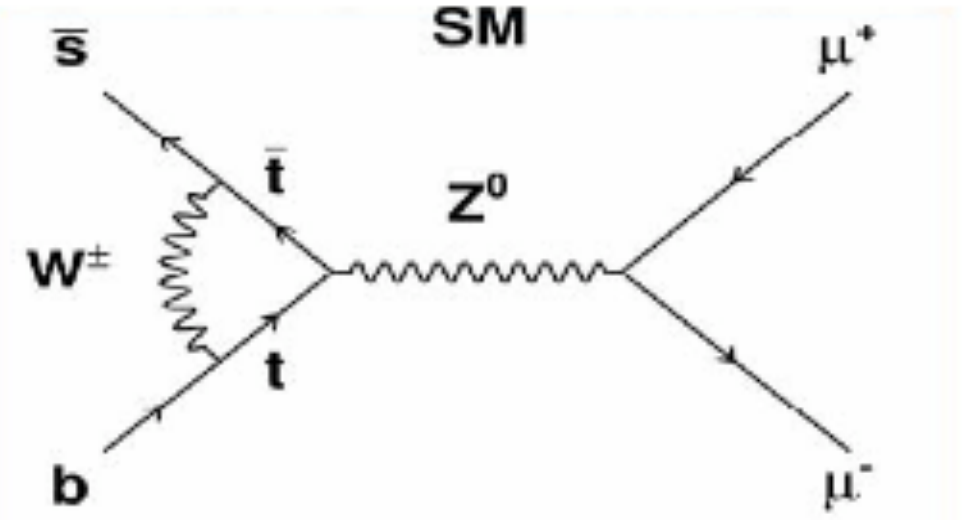
Some diagrams are further suppressed by the GIM mechanism and helicity.

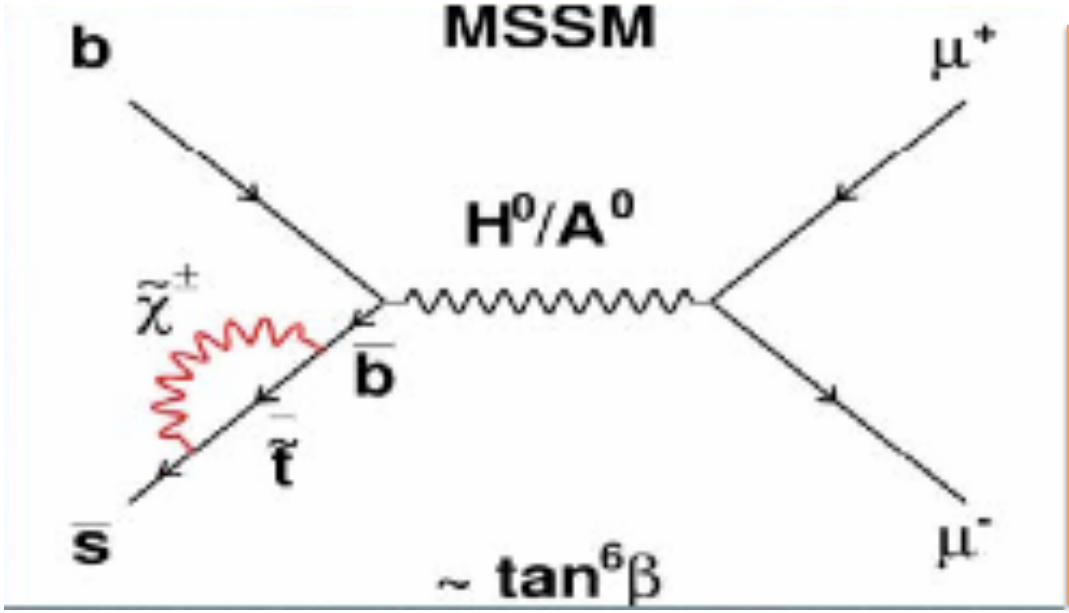
Decays otherwise conserve all quantum numbers, and are clean channels for observing new physics.

New physics can appear at tree level (RPV SUSY) or in loops (MSSM).

$B^0_{d,s} \rightarrow \mu\mu$

SM branching fraction dominated by diagrams with top quark loops.
BF ≅ 3×10^{-9} for B_s and
3×10^{-10} for B_d.

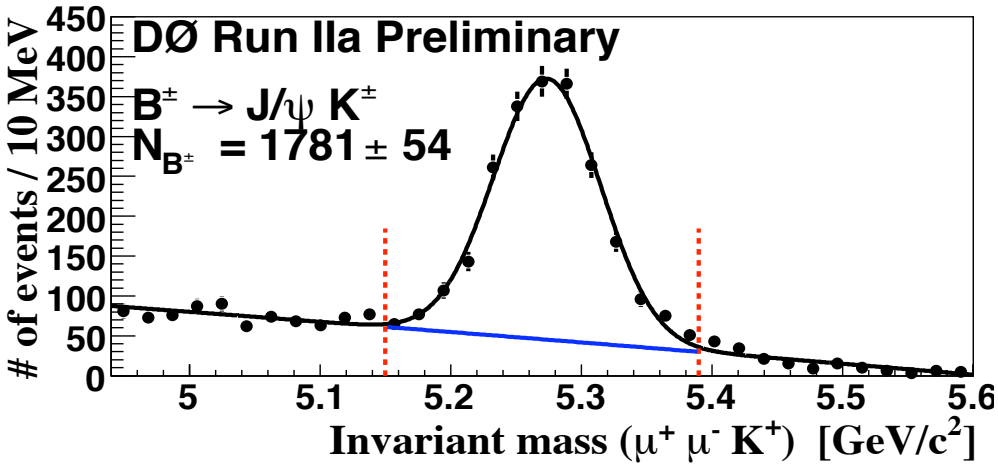


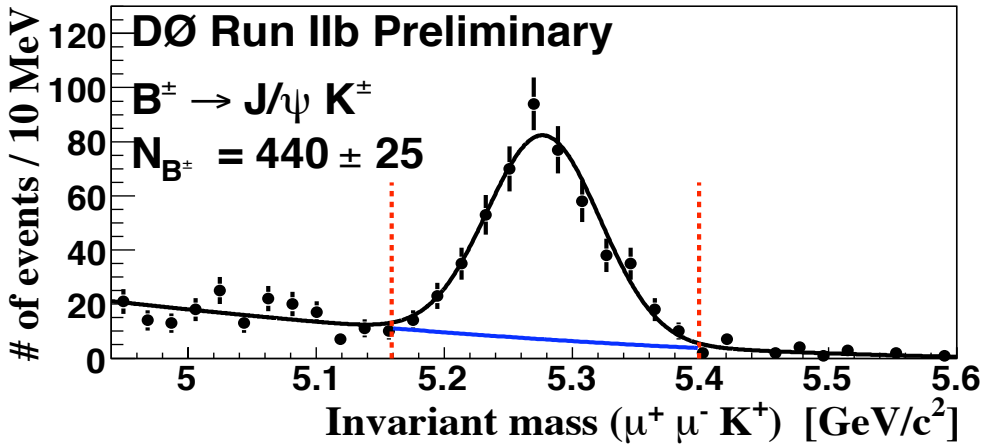


The B_s decay is particularly sensitive to supersymmetry. The branching fraction is proportional to $\tan^6\beta$ and increases the BF from the SM value.

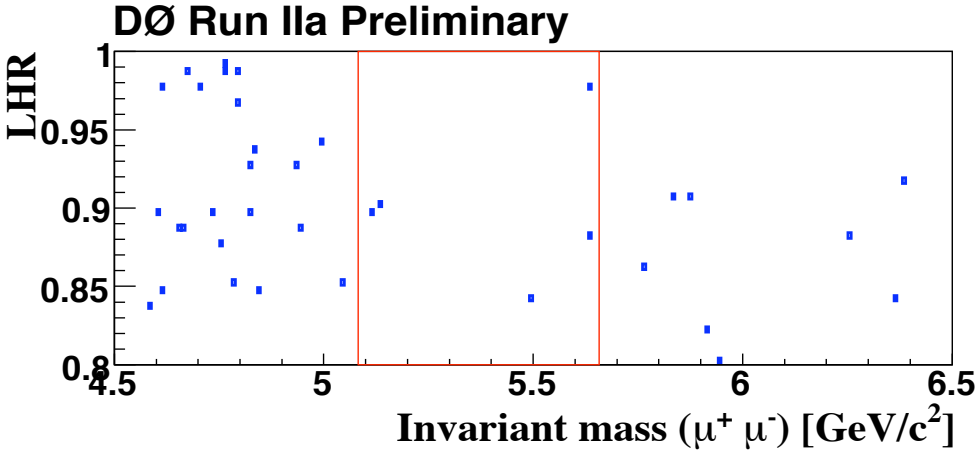
DØ $B^0_s \rightarrow \mu\mu$ Analysis

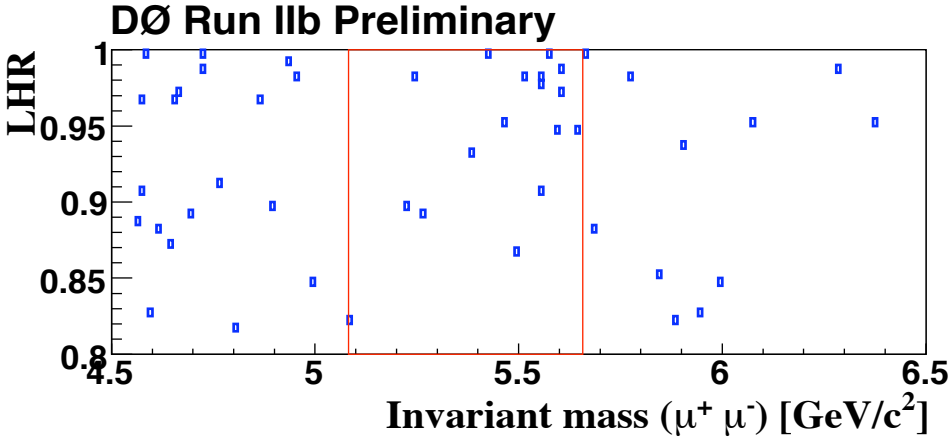
Dimuon trigger ➔ use $B^+ \rightarrow J/\psi\, K^+$ decay as reference mode.





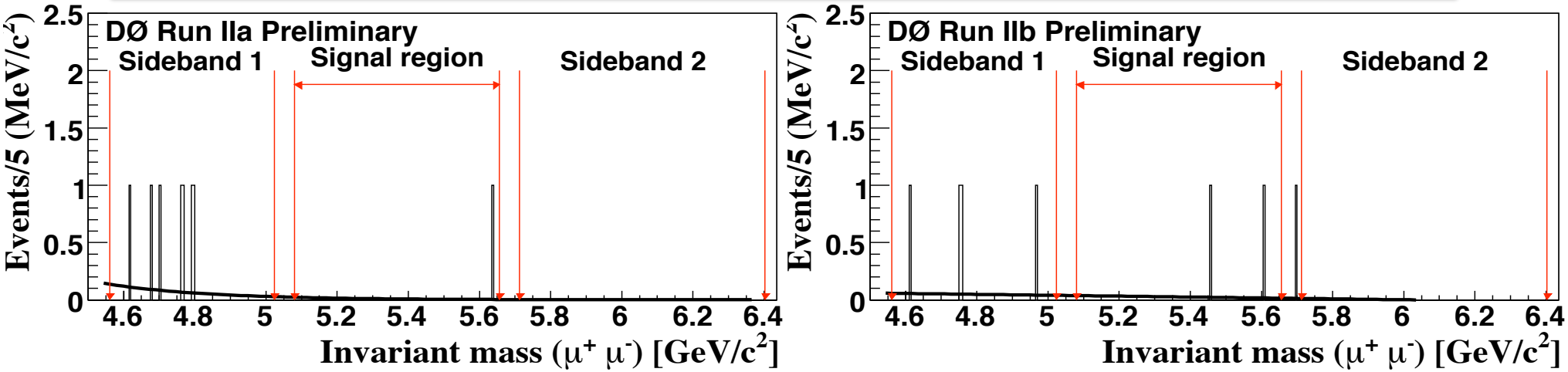
Separate sig. and bkg. with a likelihood ratio.





$B^0_{d,s} \rightarrow \mu\mu$ Results

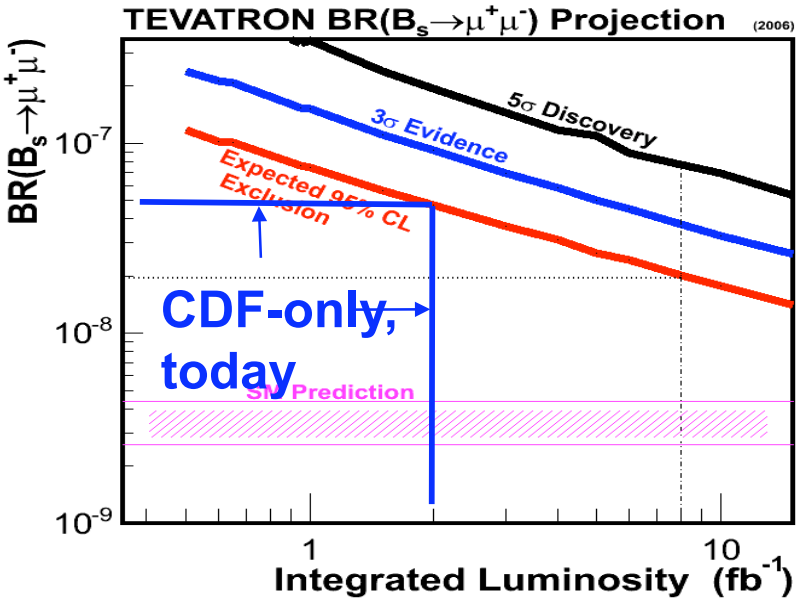
Optimized selection cuts of 0.946 (a) and 0.986 (b).

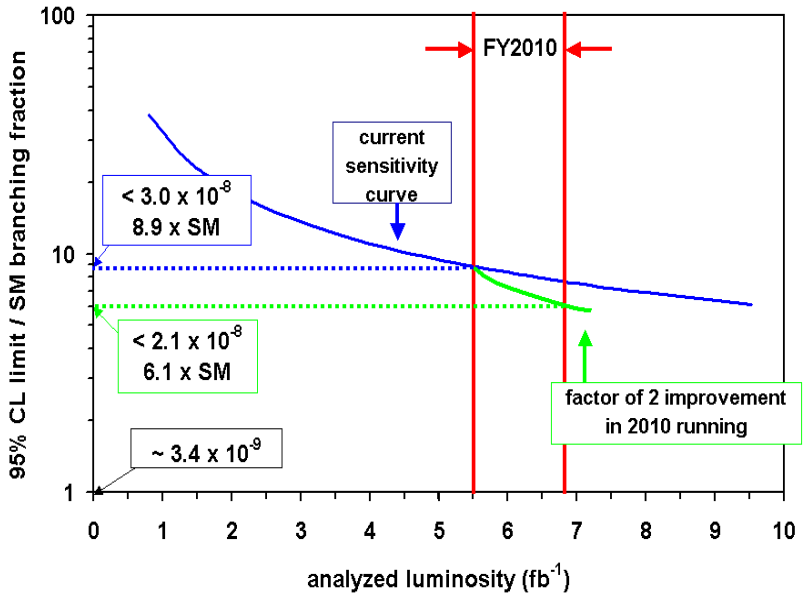


Limit 90% (95%) × 10^8	$B^0_s \rightarrow \mu\mu$	$B^0_d \rightarrow \mu\mu$
Previous best	9.4	3.9
BaBar [PRD 77, 032007 (2008)]	n/a	5.2
DØ	7.5 (9.3)	n/a
CDF [PRL 100, 101802 (2008)]	4.7 (5.8)	1.5 (1.8)

Tevatron $B_s \rightarrow \mu\mu$ Reach

- CDF extrapolates current analysis without improvements.
- DØ expects improved muon trigger
- Each experiment hits 2×10^{-8} at 7/8 fb^{-1}.
  This is just 6xSM. Corresponds to 2 SM events after all cuts. (SES 1.7×10^{-9})
- Combining results expected to push the sensitivity down to 4xSM
- Past history shows results always exceeded predictions: today CDF alone has the sensitivity previously predicted for the Tevatron.





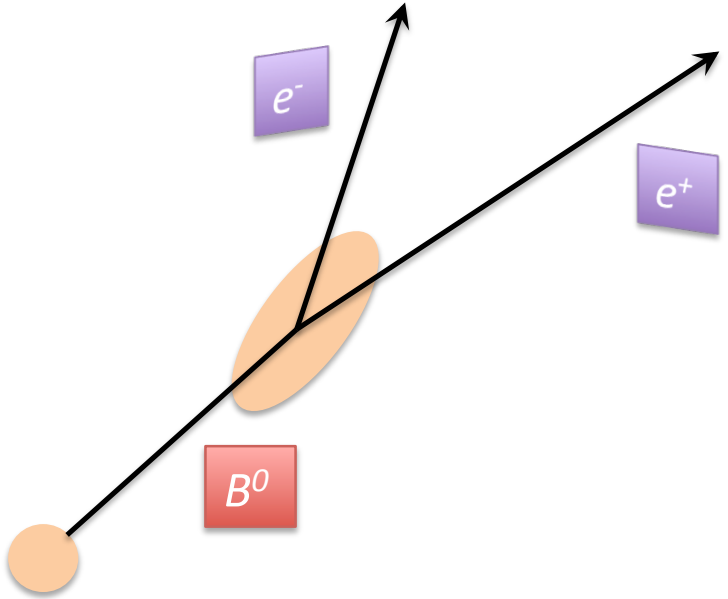
$B^0_{d,s} \rightarrow ee$

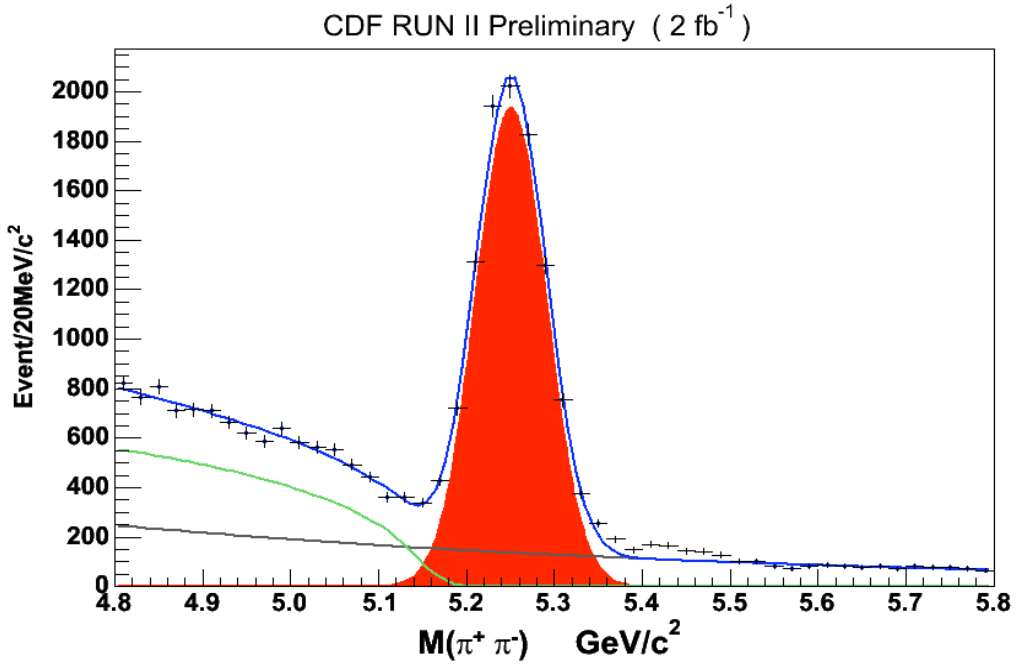
- The decay to electrons is nearly identical to the decay to muons, but the SM branching fraction is significantly smaller, of order 10^{-13} for B_s and 10^{-14} for B_d.
- NP could contribute differently to electrons than muons.

CDF $B^0_{d,s}$ → *ee* Analysis

Events selected with displaced vertex trigger (same as *B* → *hh*' analyses).

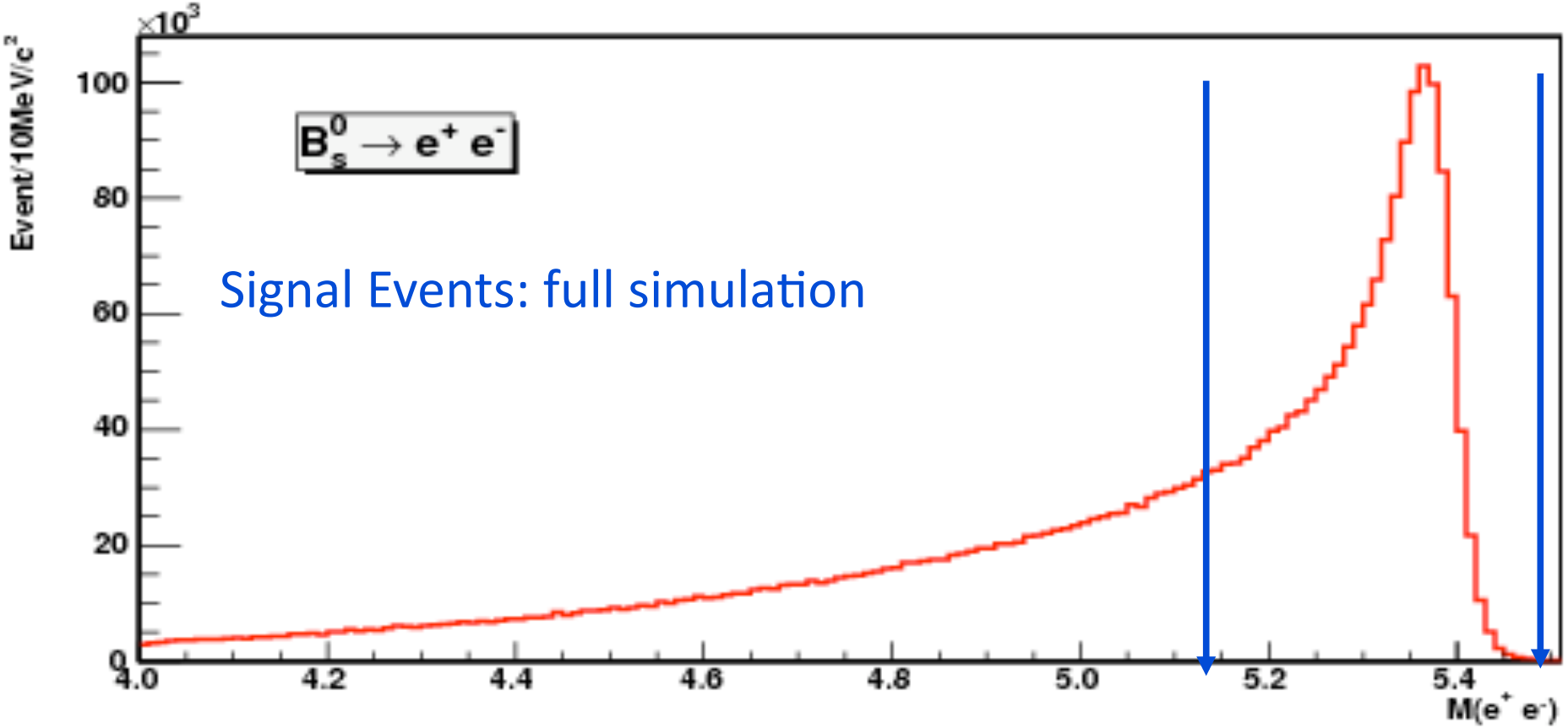
Important to factor out trigger eff.





Use B_d → Kπ sample as reference. Using separation developed for *B*→ *hh*' analysis we find 6837±214 B_d → Kπ out of 9684±225 *B*→ *hh*' decays.

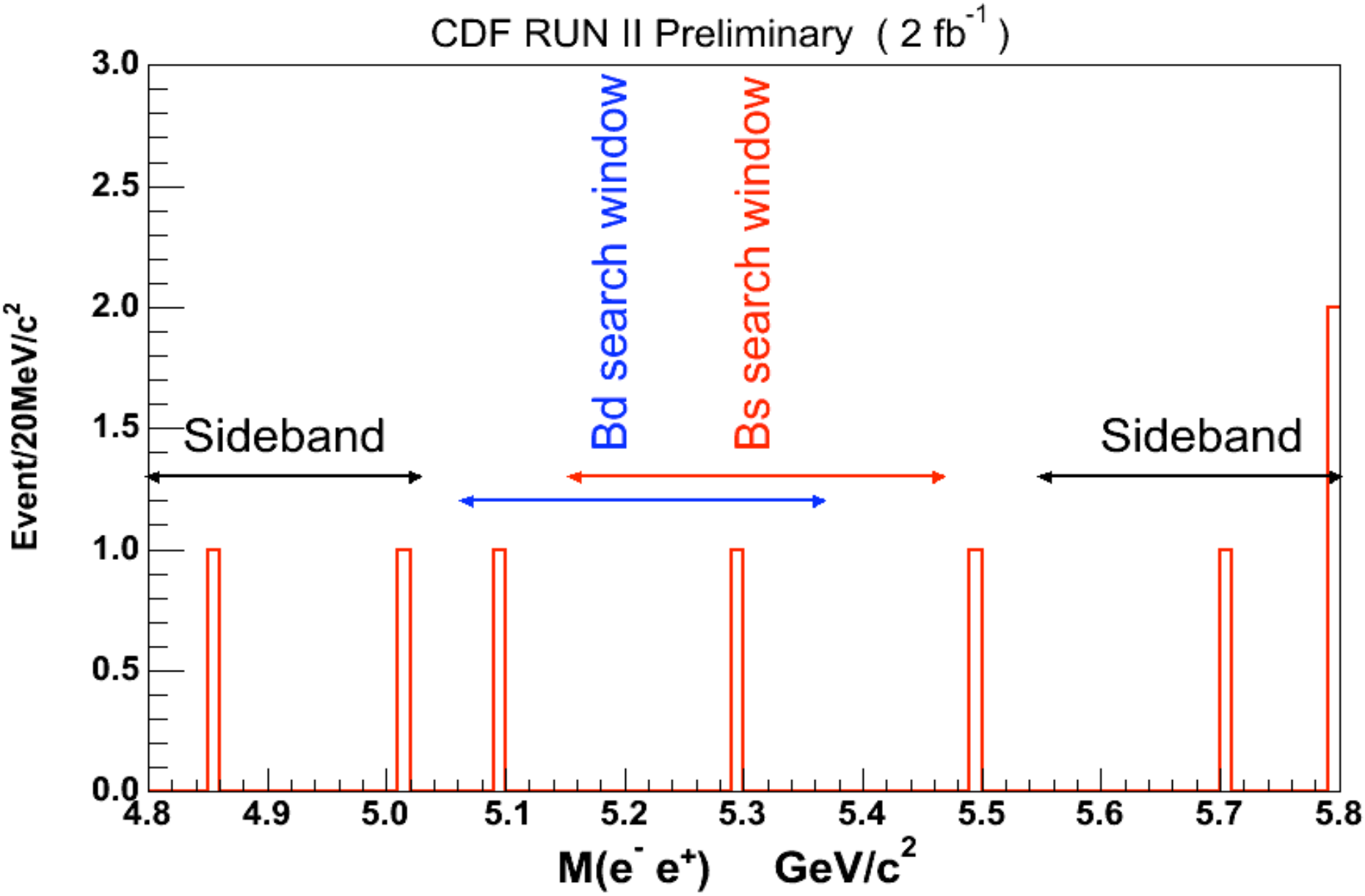
Bremsstrahlung in $B \rightarrow ee$



Long mass tail due to Bremsstrahlung.

Search window for $B_{s,d}^0 \rightarrow ee$ is (-6σ, +3σ).

$B \rightarrow ee$ Signal after Electron ID



Summary of $B^0_{d,s} \rightarrow ee$

Observe 1 event in B_s window where 2.7±1.8 bkg expected.

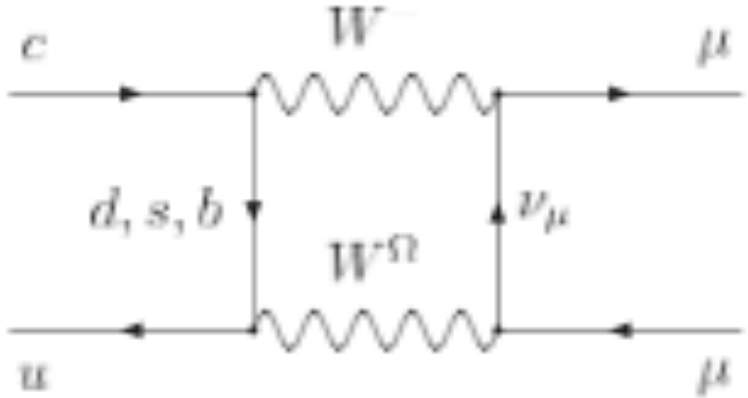
Observe 2 events in B_d window where 2.7±1.8 bkg expected.

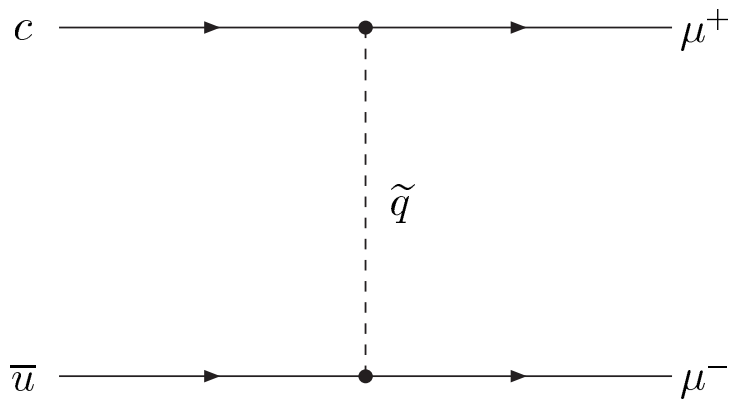
Use Bayesian method to set 90% (95%) credibility limit.

Limit 90% (95%) × 10^8	$B^0_s \rightarrow ee$	$B^0_d \rightarrow ee$
Previous best	5400	11.3
BaBar	n/a	11.3
CDF B.F. limit	28 (37)	8.3 (10.6)

$D^0 \rightarrow \mu\mu$

- The decay of the D^0 to muons is also highly suppressed – no top quark loop.
- Branching fraction dominated by long distance effects, estimated to be less than about 10^{-13}.
- Sensitive to R parity violation in SUSY. Set limit on coupling constants.

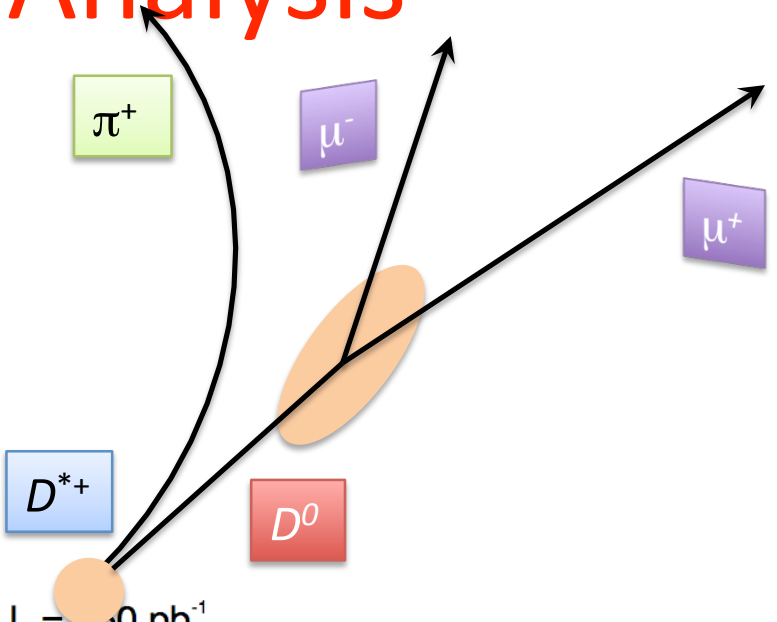


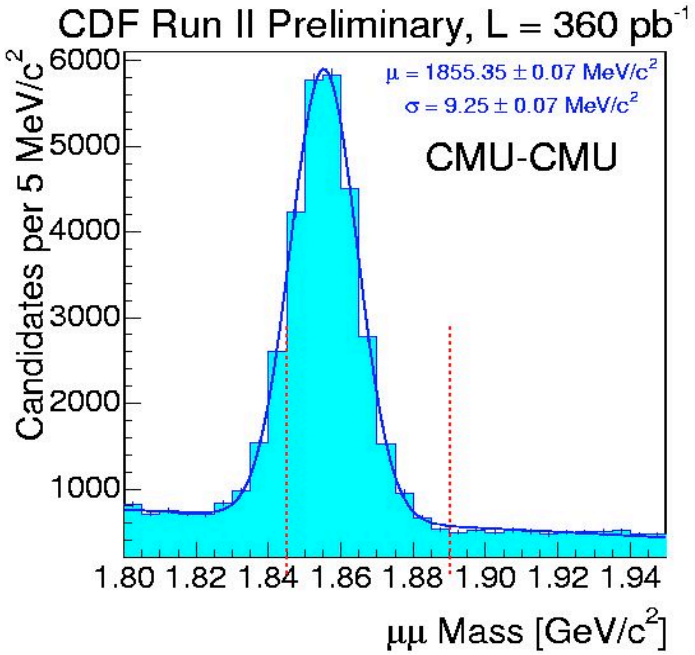


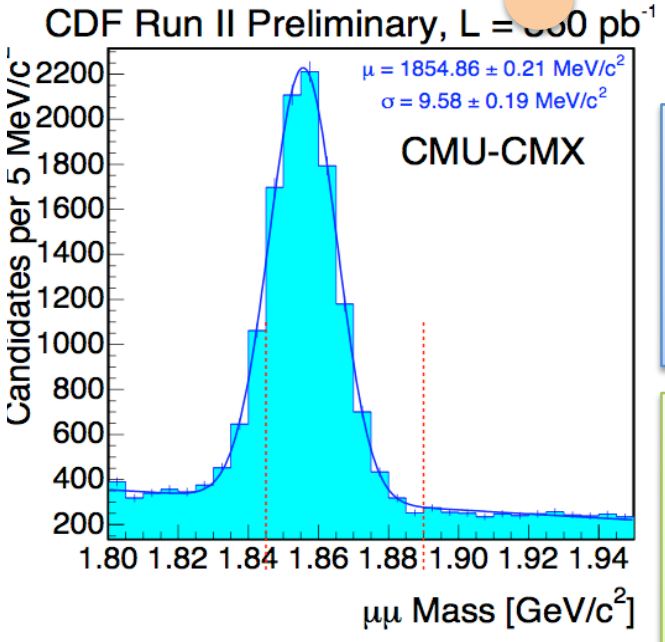
CDF $D^0 \rightarrow \mu\mu$ Analysis

Events selected with displaced vertex trigger.

D* tag provides additional background suppression.







Use central and extension muon detectors.

Divide according to detectors the tracks project to.

$D^0 \rightarrow \mu\mu$ Primary Background

Primary background comes from sequential *B* decays.

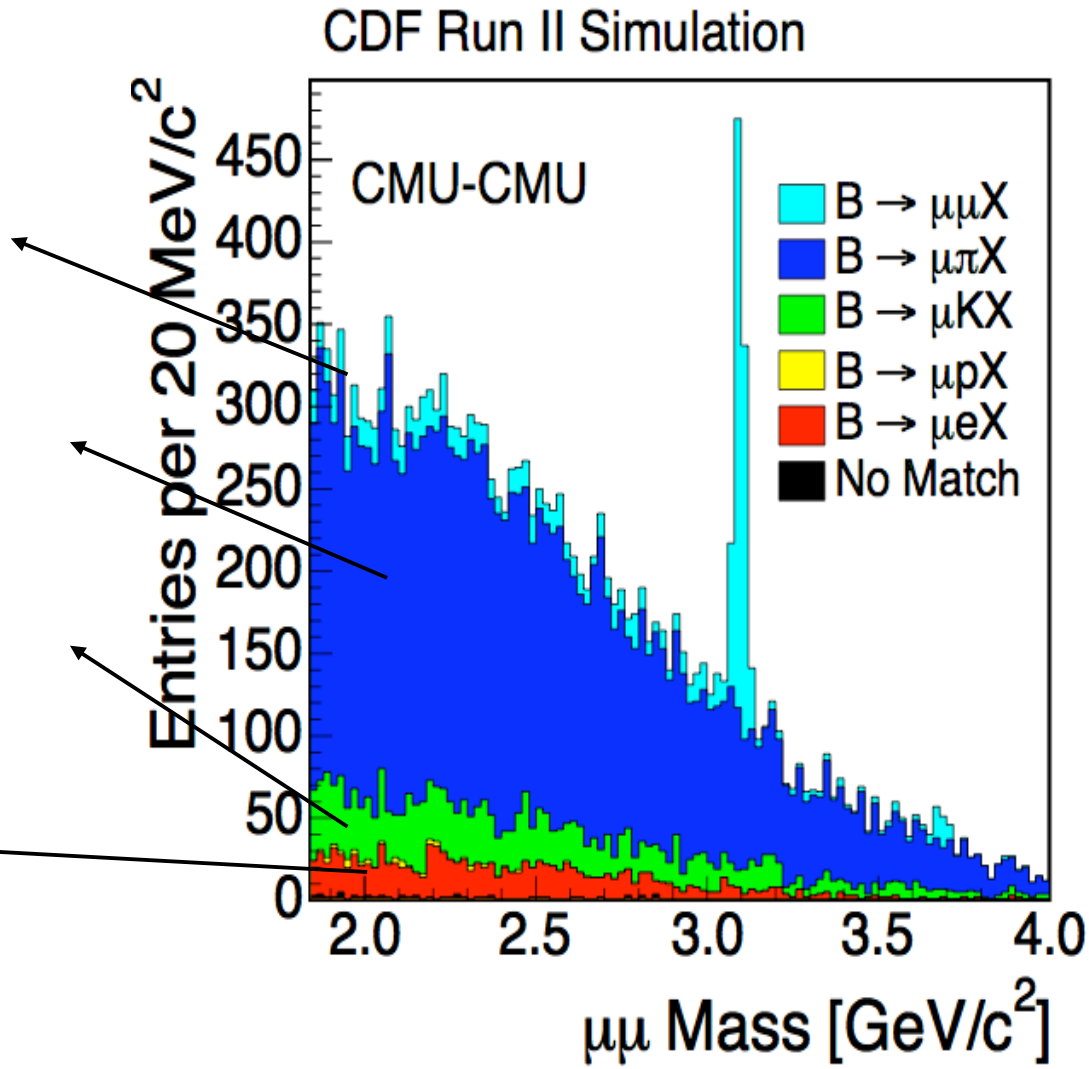
A likelihood ratio is used to suppress sequential *B* decays.

×100%

× ~0.5%

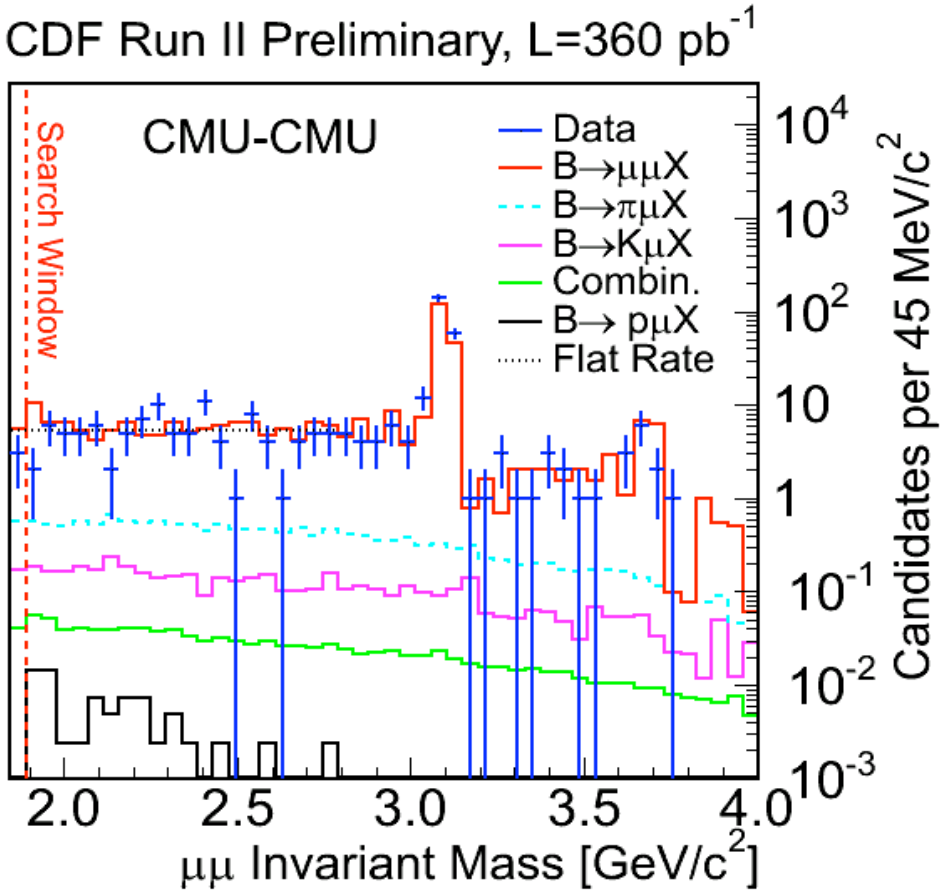
× ~1.0%

× 0%

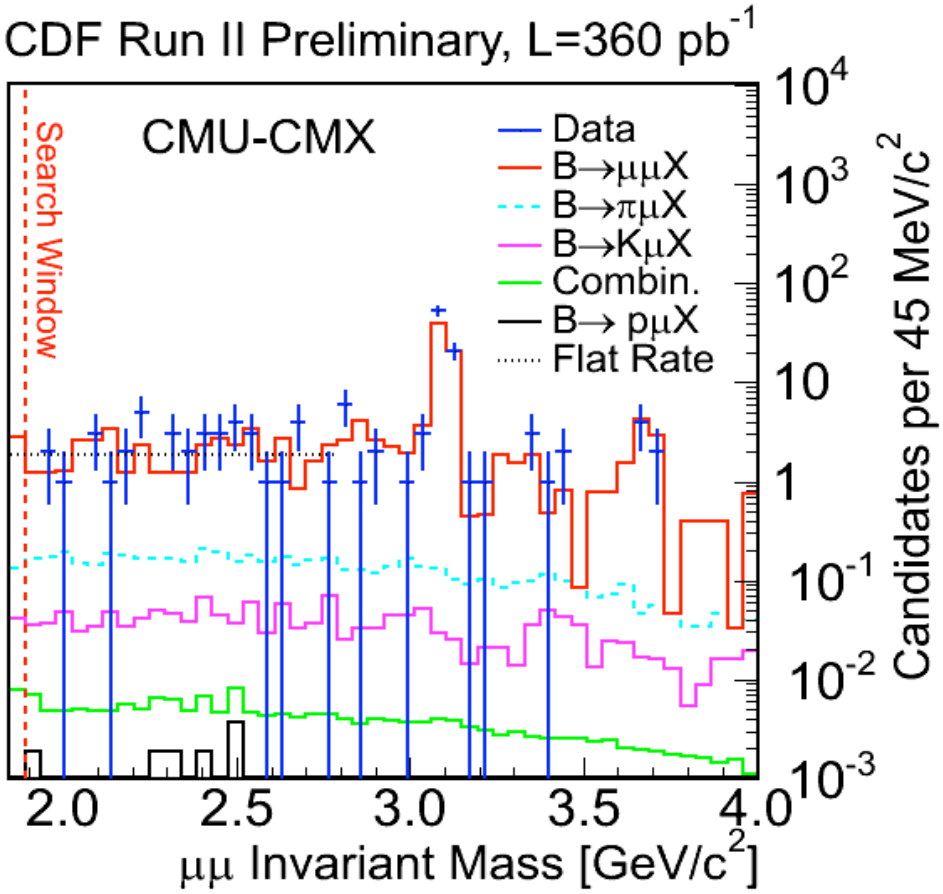


$D^0 \rightarrow \mu\mu$ Mass Plot after Lepton ID

Both muons in $|\eta| < 0.6$



One muon in $|\eta| < 0.6$, and one in $0.6 < |\eta| < 1.0$



Summary of $D^0 \rightarrow \mu\mu$ Results

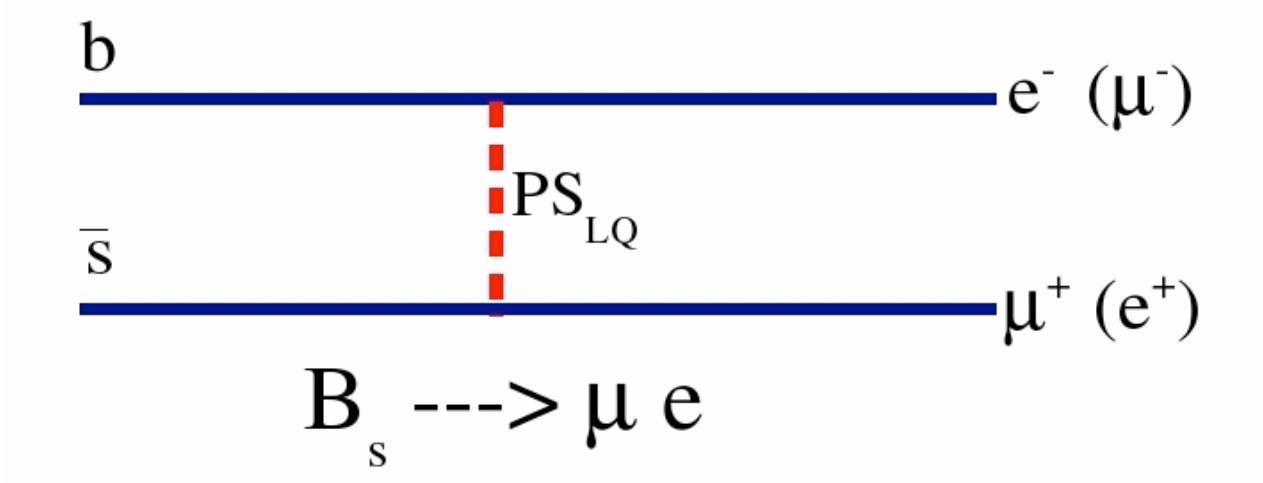
	CMU-CMU	CMU-CMX	CMX-CMX
Exp. Bkg	4.9 ± 1.3	2.74 ± 0.96	1.04 ± 0.48
Observed	3	0	1

$$\mathcal{B}(D^0 \rightarrow \mu^+\mu^-) \leq \frac{N_\alpha(D^0 \rightarrow \mu^+\mu^-)}{N(D^0 \rightarrow \pi^+\pi^-)} \frac{\epsilon_{\pi\pi}}{\epsilon_{\mu\mu}} \mathcal{B}(D^0 \rightarrow \pi^+\pi^-)$$

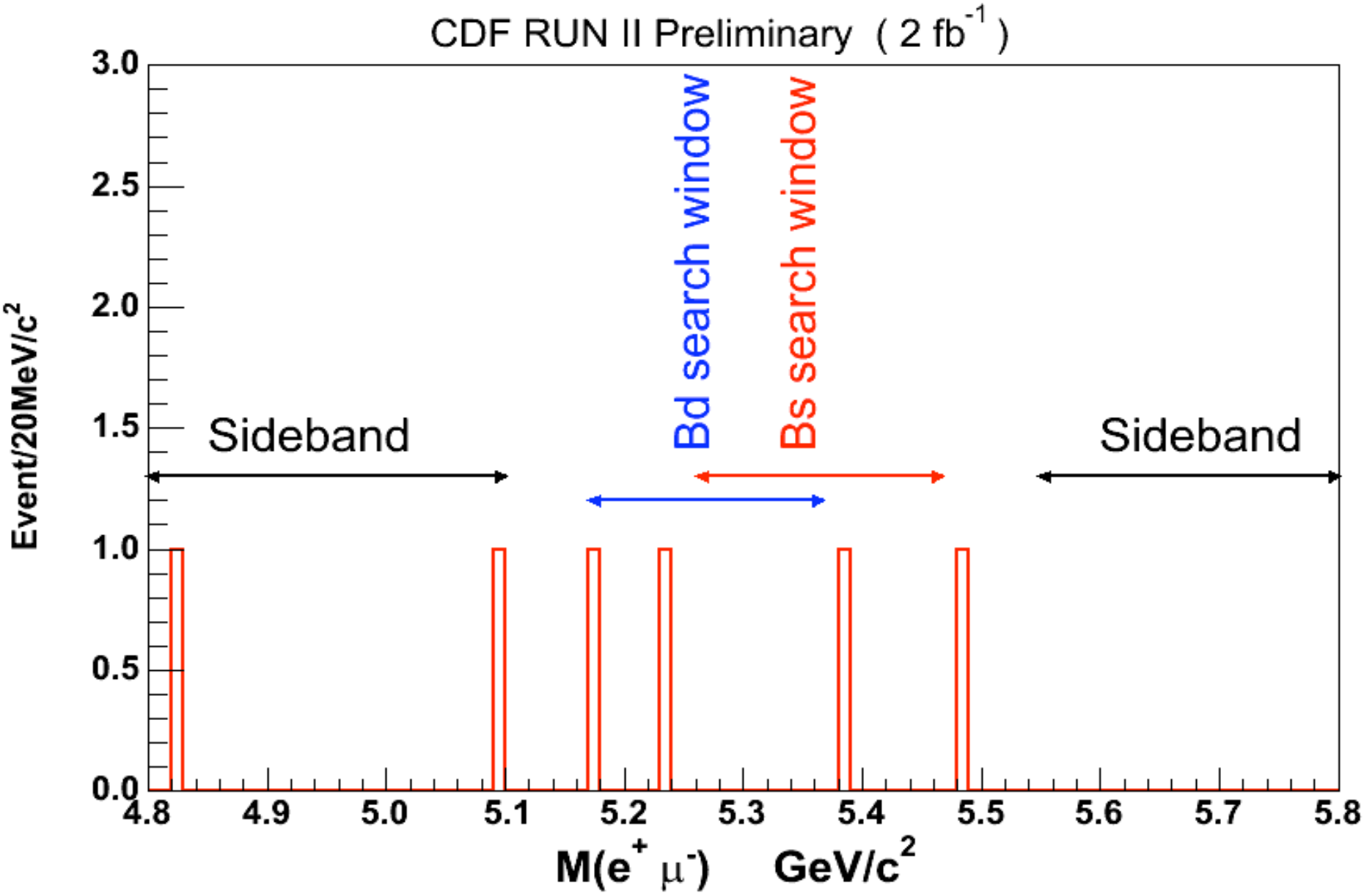
$Br(D^0 \rightarrow \mu\mu) \times 10^7$	90% Limit	95% Limit
HERA-B [PLB 596, 173 (2004)]	20	n/a
BaBar [PRL 93, 191801(2004)]	13	n/a
CDF	4.3	5.3

Lepton-Flavor Violating Decays

- Forbidden in the SM, observation of these decays signals new physics.
- Possible new physics sources include Pati-Salam leptoquarks and R parity violating SUSY.



$B \rightarrow e\mu$ Signal after Lepton ID



Summary of $B^0_{d,s} \rightarrow e\mu$

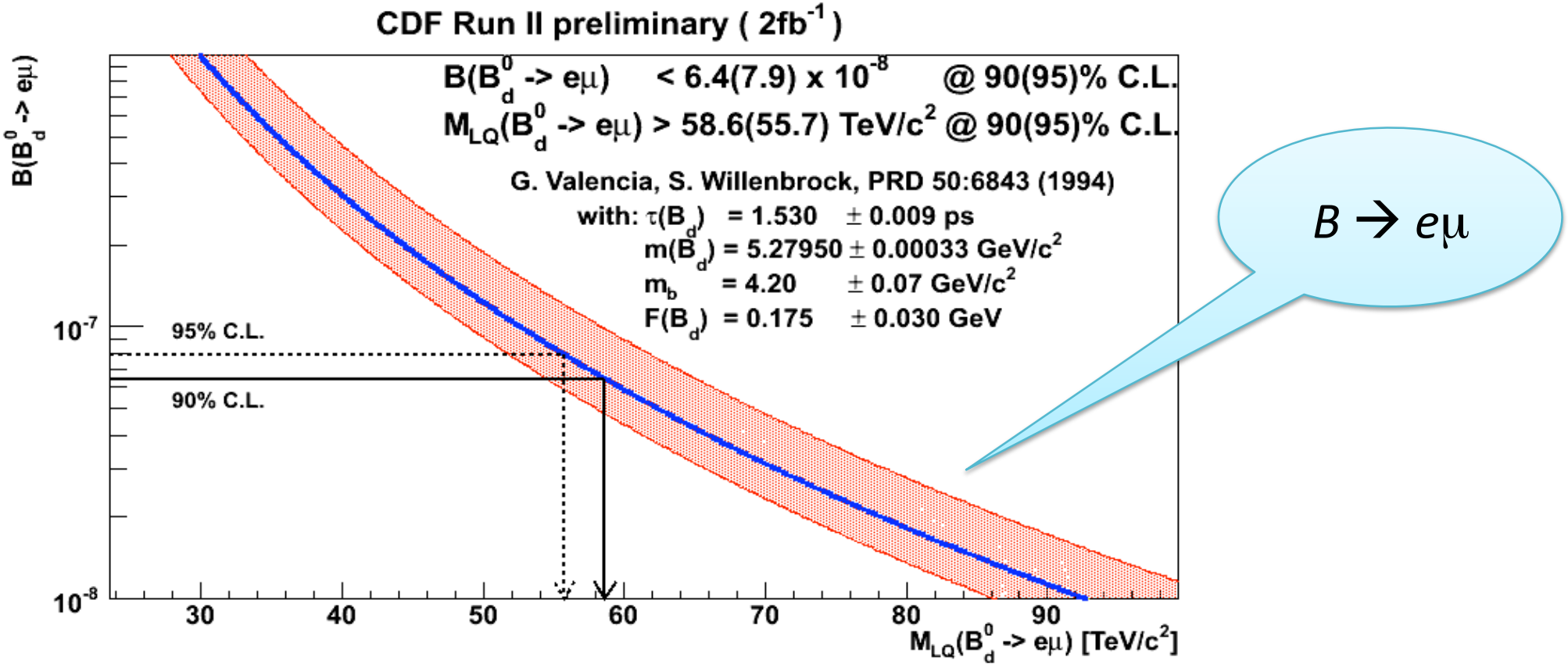
Observe 1 event in B_s window where 2.7±1.8 bkg expected.

Observe 2 events in B_d window where 2.7±1.8 bkg expected.

Use Bayesian method to set 90% (95%) credibility limit.

Limit 90% (95%) × 10^8	$B^0_s \rightarrow e\mu$	$B^0_d \rightarrow e\mu$
Previous best	610	9.2
BaBar [PRD 77, 032007 (2008)]	n/a	9.2
CDF	20 (26)	6.4 (7.9)

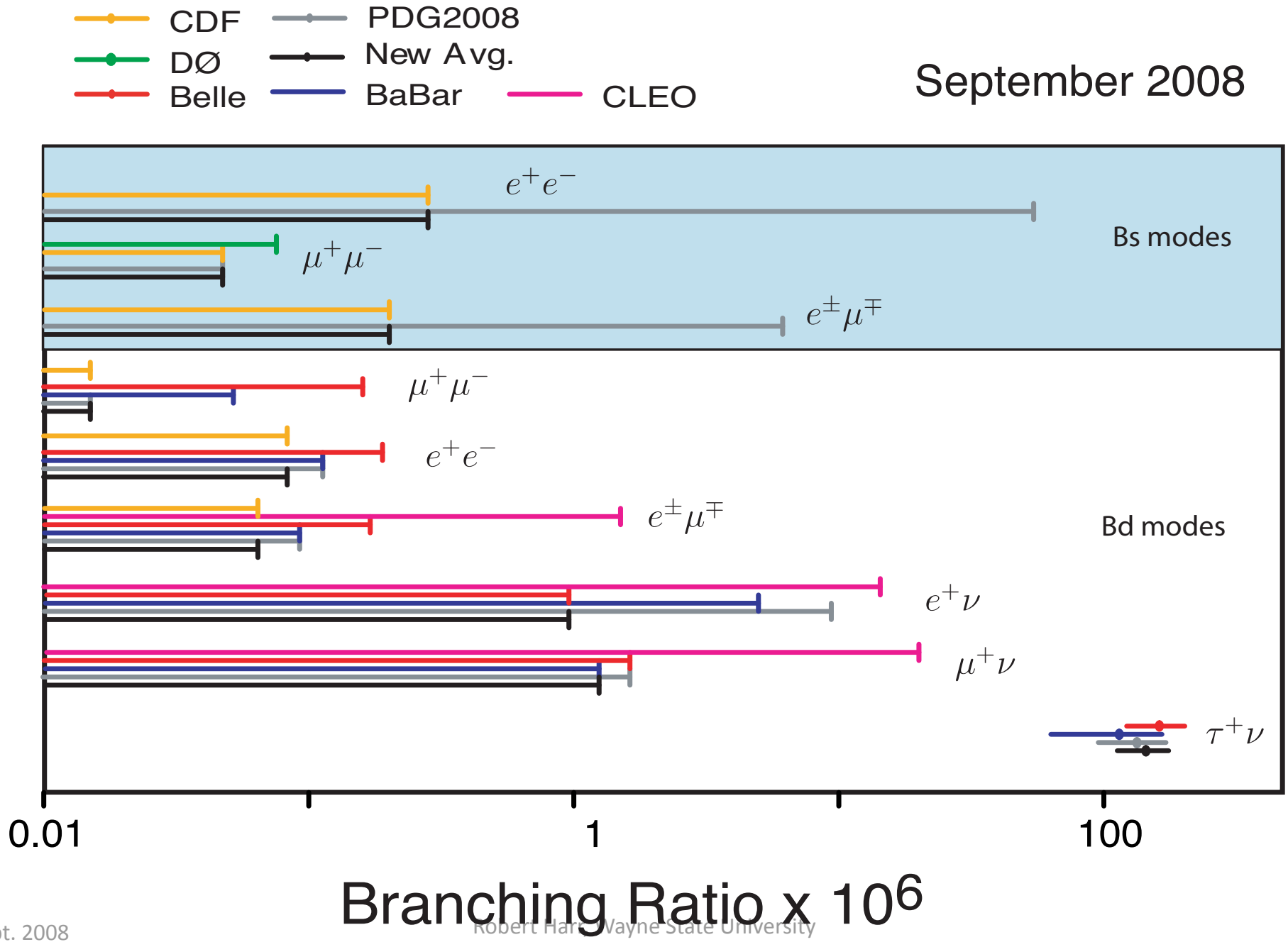
PS Leptoquark & RPV Couplings



From $\mathcal{B}(D^0 \rightarrow \mu\mu)$ result, limit RPV SUSY couplings:

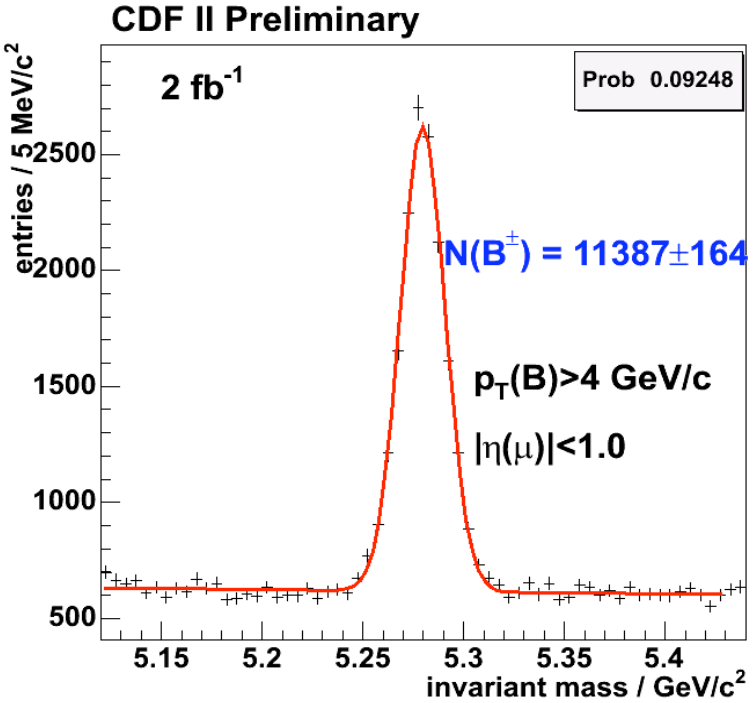
$$\widetilde{\lambda}'_{21k}\widetilde{\lambda}'_{22k} < 6\sqrt{\mathcal{B}(D^0 \rightarrow \mu^+\mu^-)} = 3 \times 10^{-3}$$

Purely Leptonic B Decay Modes



Backup

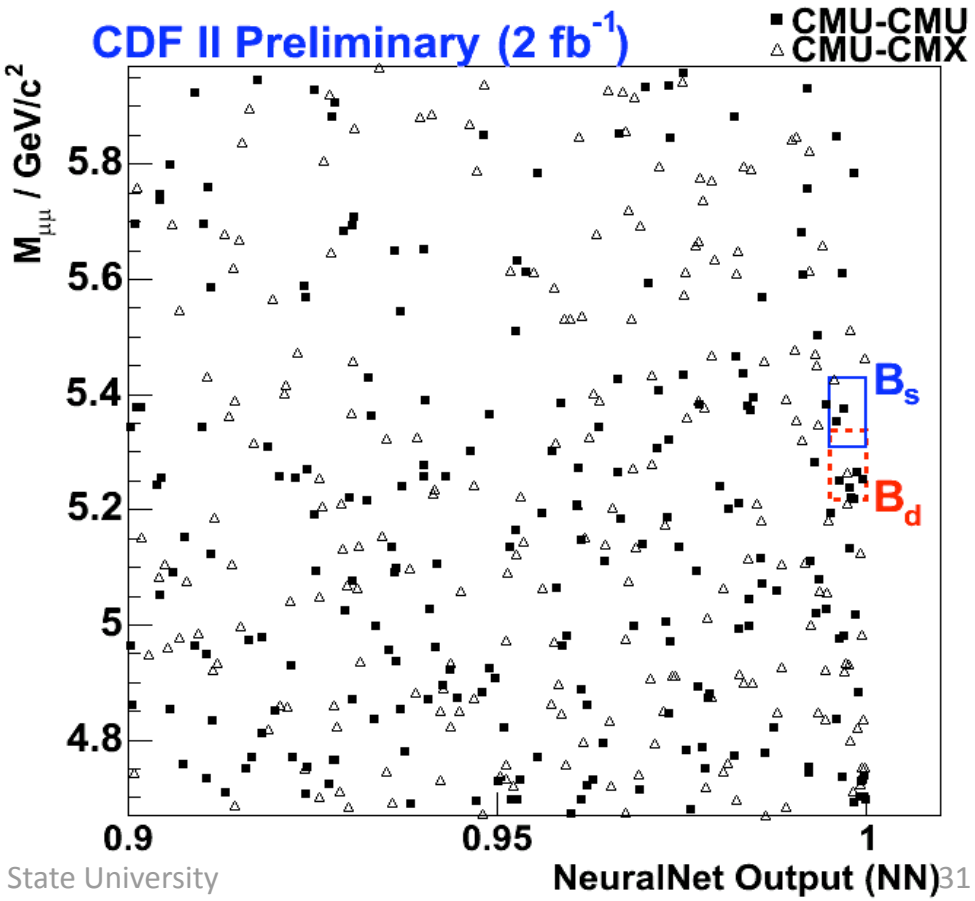
CDF $B^0_{d,s} \rightarrow \mu\mu$ Analysis



We measure relative to a reference mode $B^+ \rightarrow J/\psi\, K^+$. All events selected on dimuon trigger.

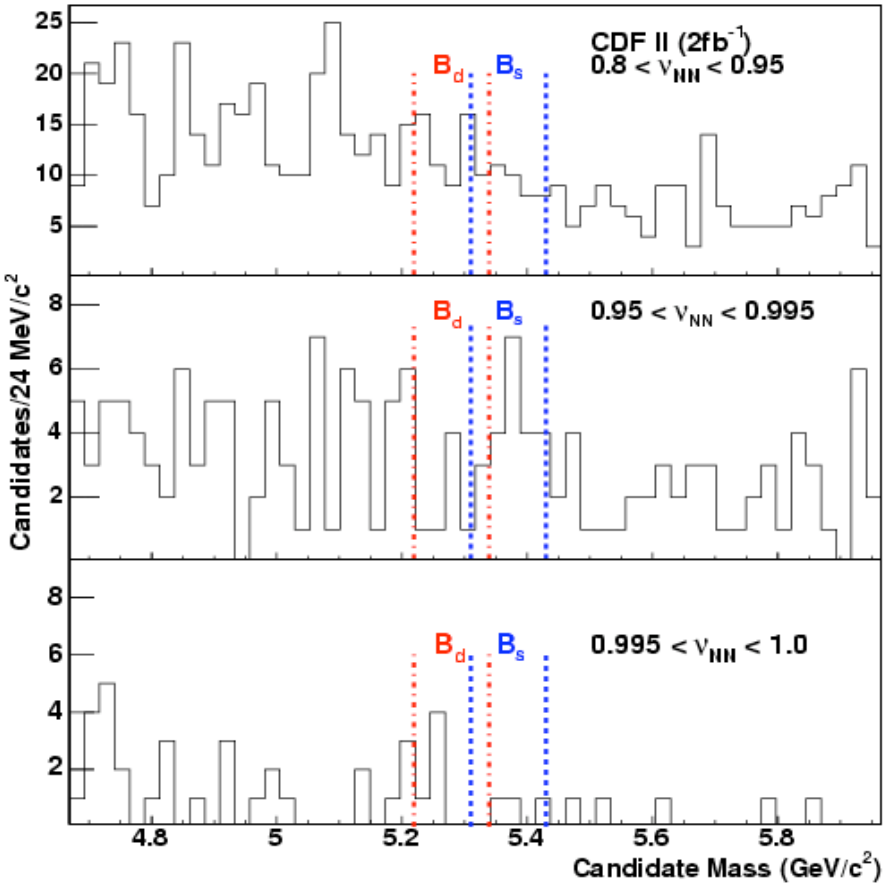
Neural net is used to enhance signal.

Selection: decay time and significance, isolation, and pointing.

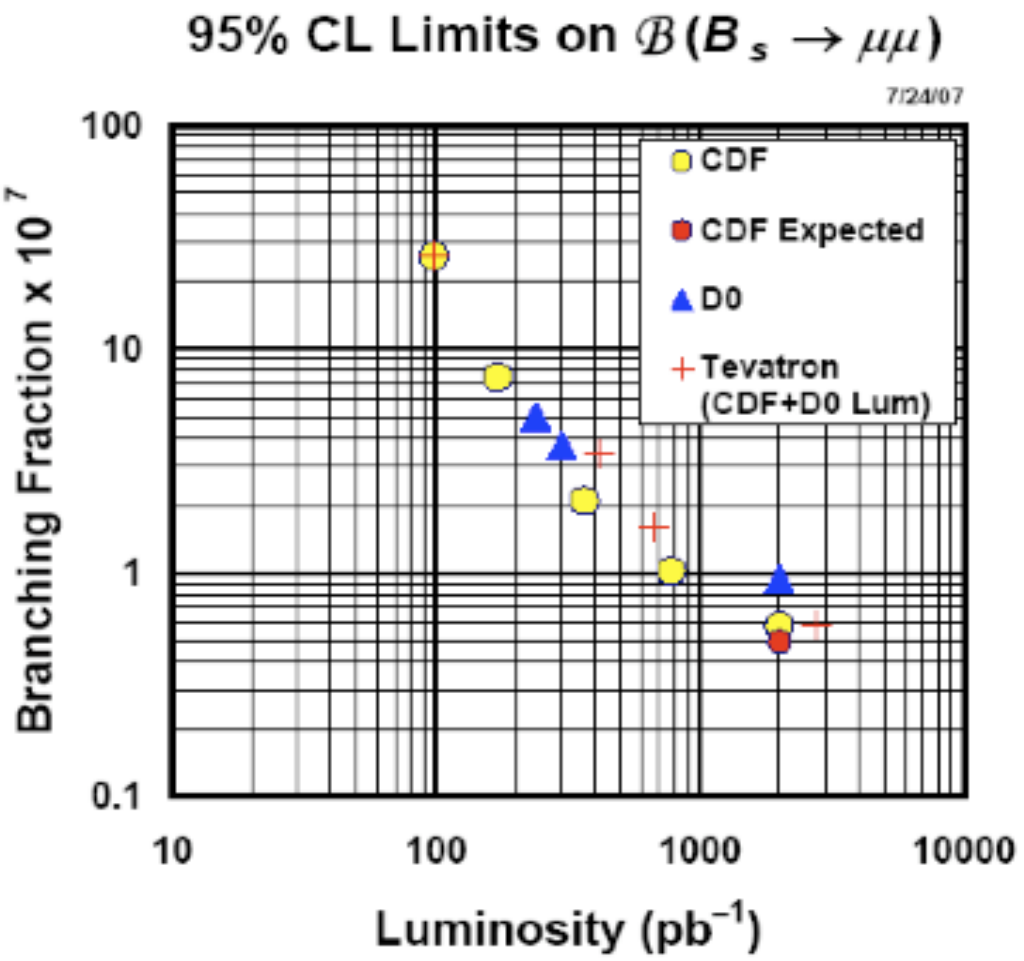


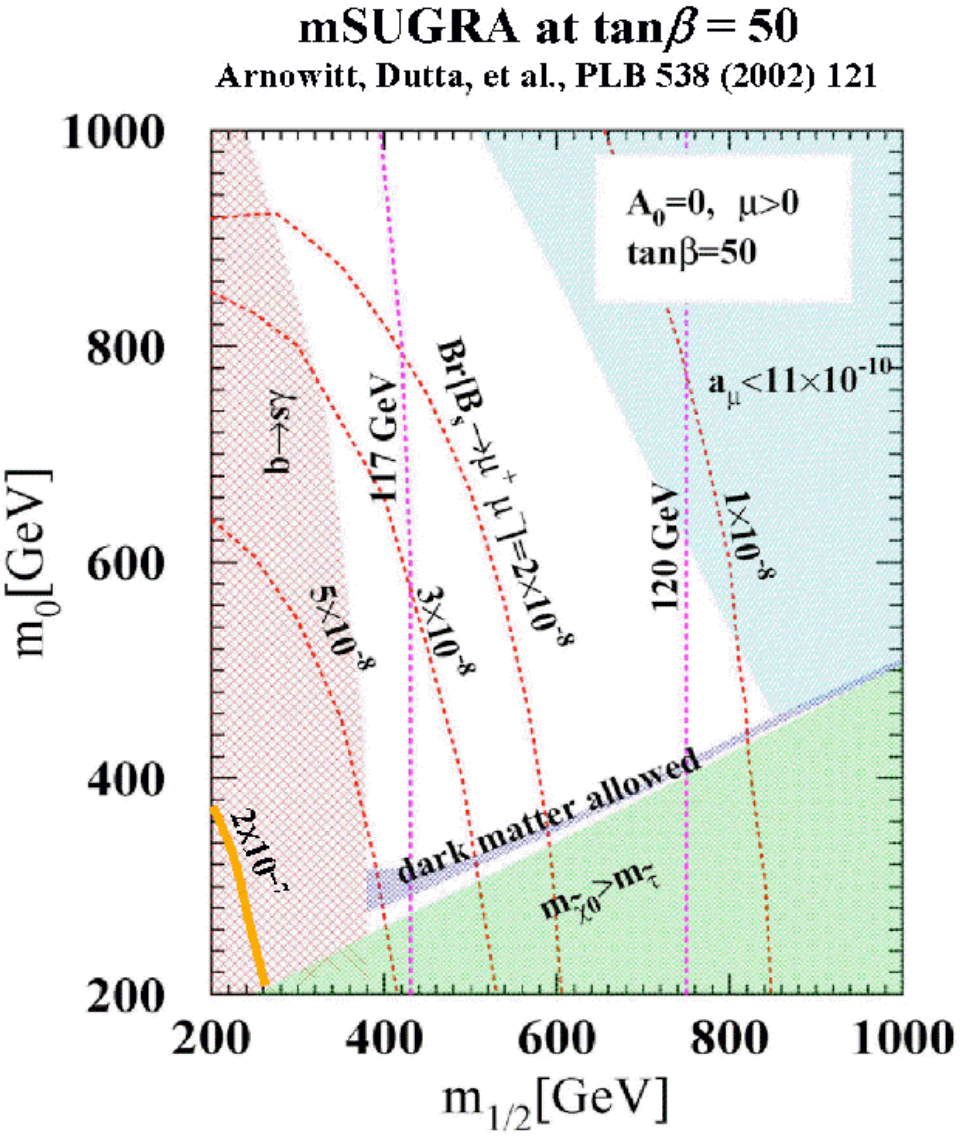
CDF $B^0_{d,s} \rightarrow \mu\mu$ Analysis (cont'd)

Limit is calculated using 5 bins in mass and 3 in neural net output from 0.8 to 1.0.

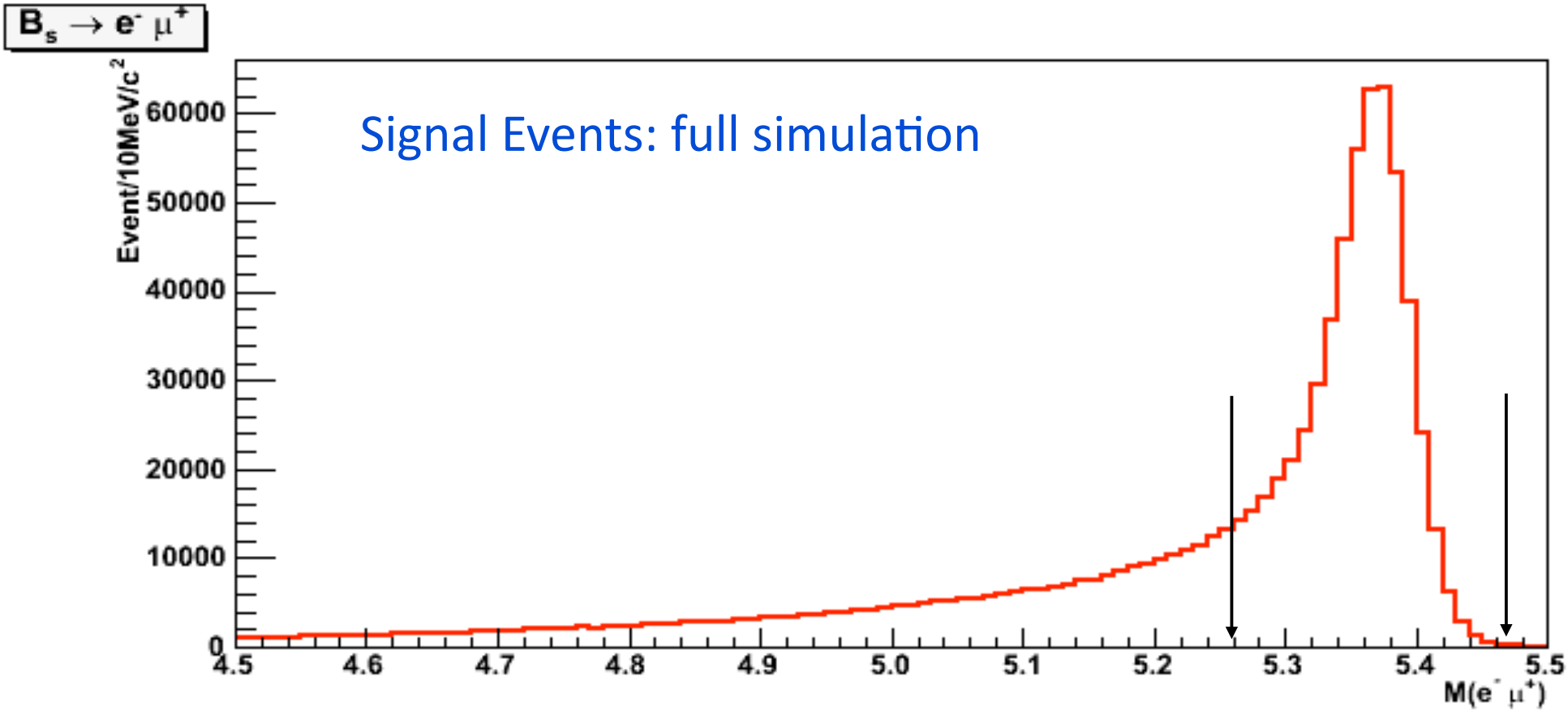


$B^0_s \rightarrow \mu\mu$ Prospects and New Physics





Bremsstrahlung in $B \rightarrow e\mu$



Long mass tail due to Bremsstrahlung.

Search window for $B_{s,d}^0 \rightarrow e\mu$ is $\pm 3\sigma$ around $B_{s,d}^0$ mass.