Search for Rare Decays $B_s \rightarrow \mu^+\mu^-$ and $B_d \rightarrow \mu^+\mu^-$ Using CDF Run2 Data

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***For* CDF Collaboration**

May 28, 2004

Chicago Flavor Seminar

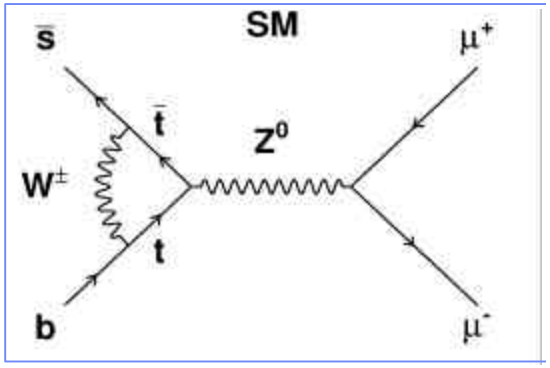
Fermilab

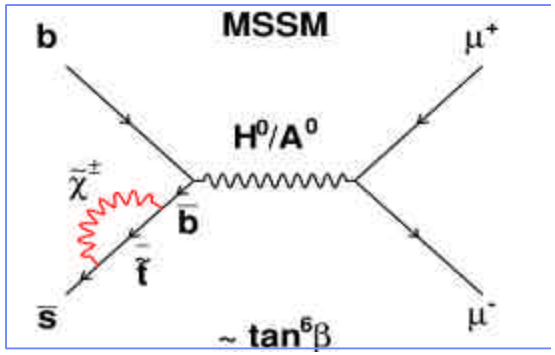
Outlines

- Introduction
  - Theoretical motivations.
  - Existing limits
- CDF Run2
- Br($B_{s(d)}$→μ+μ-) measurement.
  - Blind analysis.
  - Signal & Background
    - **Discriminating variables**
  - Background estimation method.
- Acceptance and efficiency
- Optimization → Expected limit
- Observed limit
- Summary and plans

Theoretical motivations. Current limits.

- Flavor Changing Neutral Current.
  Loop contribution only in SM.
  - $Br_{SM}(B_s \to \mu^+\mu^-) = (3.4 \pm 0.5) \times 10^{-9}$
  - $Br_{SM}(B_d \to \mu^+\mu^-) = (1.00 \pm 0.14) \times 10^{-10}$ (hep-ph/0303060)
- Only upper experimental limit exists:
  - $Br_{exp}(B_s \to \mu^+\mu^-) < 2.0 \times 10^{-6}$ 90% C.L. CDF RunI @100/pb.
  - $Br_{exp}(B_d \to \mu^+\mu^-) < 1.6 \times 10^{-7}$ 90% C.L. Belle '03 @78/fb.



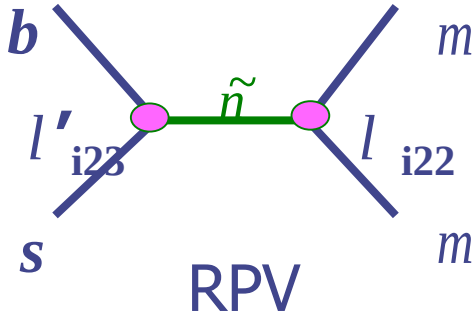


mSUGRA,SO(10)

- Limits are far away from the SM value: can test for a possible new physics.

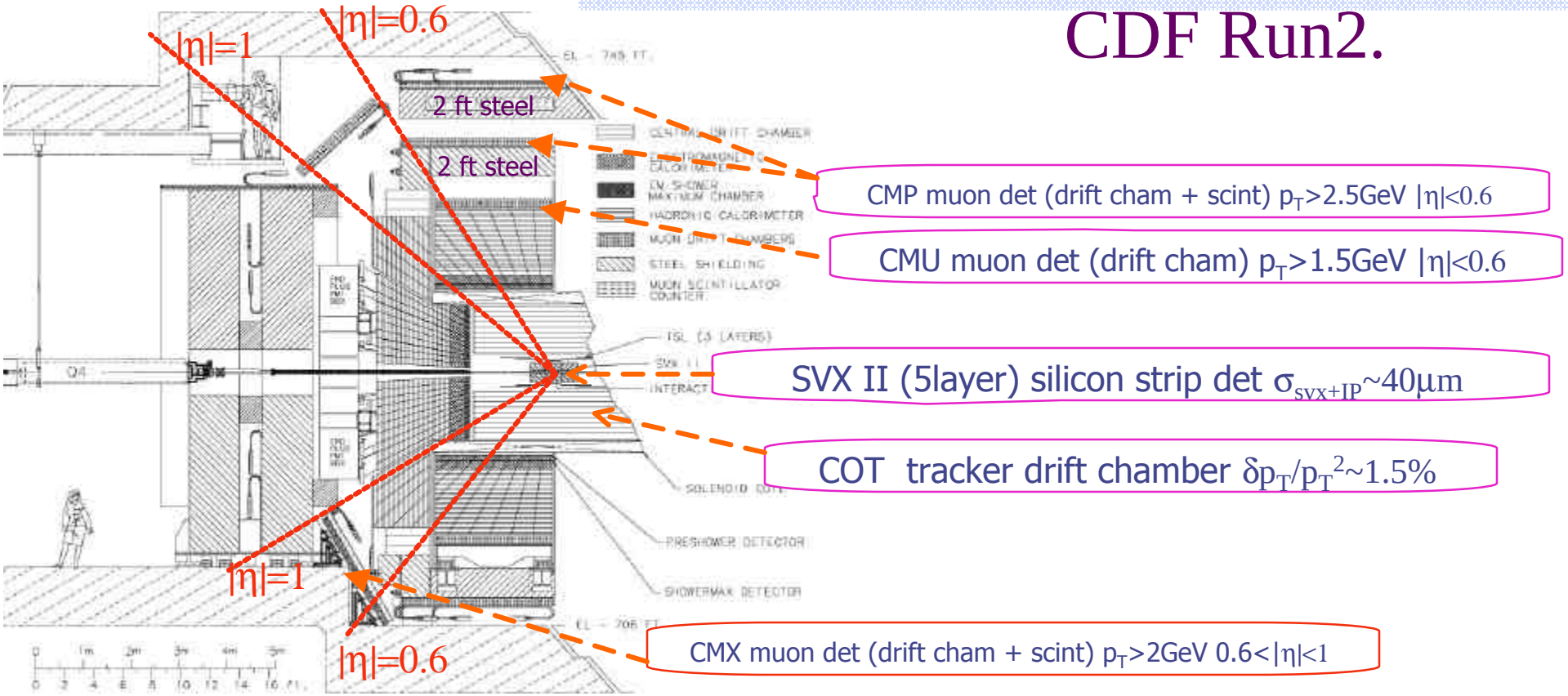
- MSSM: $Br(B \to \mu^+\mu^-)$ enhanced by $\tan\beta > 10$ terms $\sim \tan^6\beta$. Up to 100 over the SM prediction.
- R-parity violating models give tree level contributions. Not heavily constrained by other observables.

- Can be seen in Run2



- Other models enhance less. E.g., universal extra dimensions. Up to +70% for $B_s \to \mu^+\mu^-$

CDF Run2.



- ☞ $\sqrt{s}$=1.96TeV s(Inelastic)~60mb. L ~$6*10^{31}cm^{-2}s^{-1}$ (~$230pb^{-1}$ good recorded)
  - ➢Plan: ~$8*10^{31}cm^{-2}s^{-1}$ (Run2a); ~$2*10^{32}cm^{-2}s^{-1}$ (4-8/fb Run 2)
- ☞ 1.7MHz collision→20kHz L1 trigger→350Hz L2→60Hz L3/logging rate.
  - ➢~80% L1 (~1/3 at L3) of the triggers are B physics

Run2 vs Run1

- ☞ Better silicon coverage (x2), muon detection, improved tracking.
- ☞ Better triggers: lower track p_T, higher efficiency.

$Br(B_{s(d)} \rightarrow \mu+\mu-)$ measurement.

CL=90% upper limit on $<n_{sig}>$ for n_{obs} and n_{bg}

171pb-1 or 10 trillion collisions

$$BR(B_s \rightarrow \mu\mu) \leq \frac{N_{CL}(n_{obs}, n_{bg})}{2 \cdot a \cdot e_{total} \cdot s_{Bs} \cdot \int Ldt}$$

only Run1 σ_{Bs}=0.9μb for p_T^{Bs}>6 GeV/c, |y|<1
(use this as a baseline selection)

3% (CMU&CMP Run1)

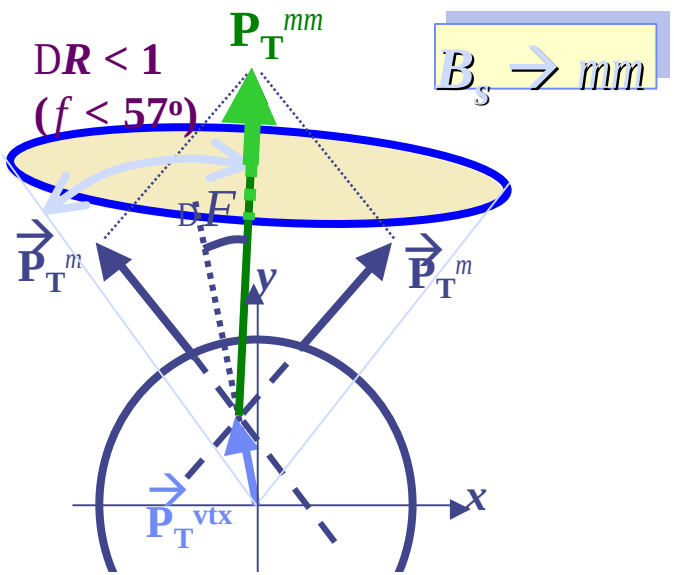
25% Run1

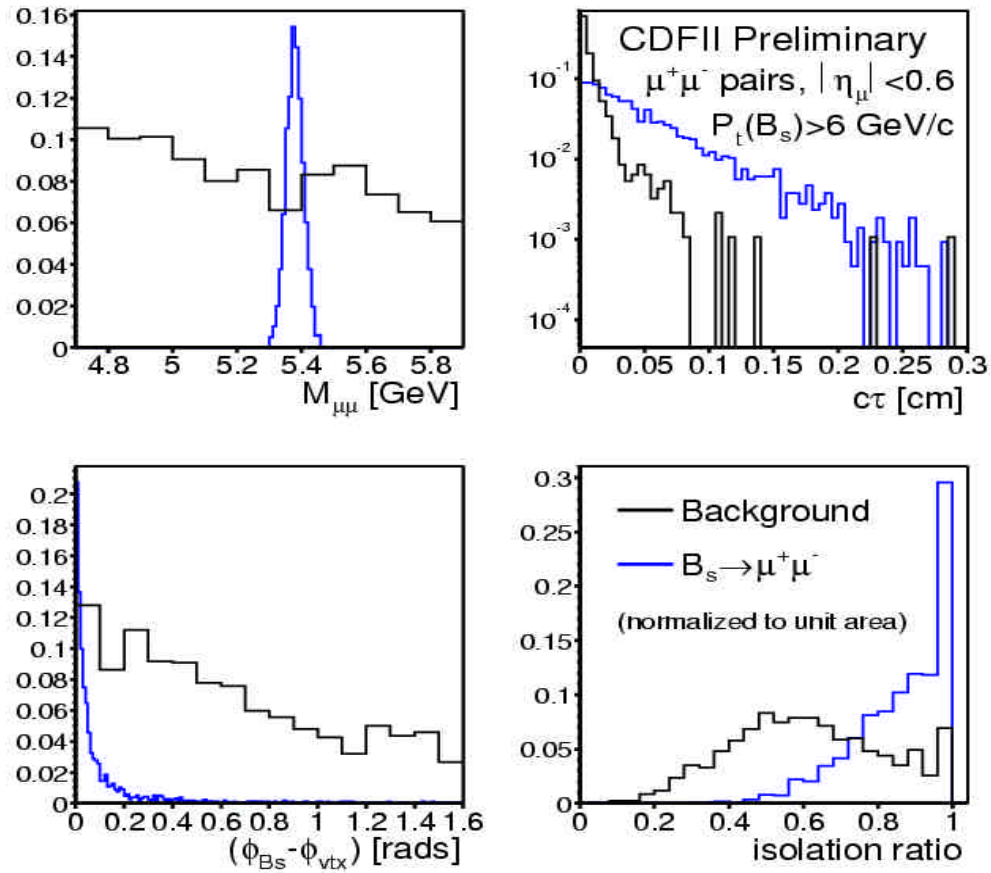
Dimuon trigger and p_T>6GeV
baseline sample: 2940 events

- Expect to detect at most few events that might only look like $B_{s(d)} \rightarrow \mu+\mu-$
- SM predicts 0 events ⇒ really a "search"
  - emphasis on performing an unbiased optimization
- Don't look at the data signal region (blind search)
  - Signal inside $5.169<M_{\mu\mu}<5.469$ GeV/c^2 (±3σ window)
- demonstrate understanding of background events
- accurately estimate α (acceptance) and ε (efficiency)
- intelligently optimize cuts

Signal & Background

☞ Need to select discriminating variables that leave most of the signal and remove most of the background.





Most Promising Discriminating Variables

- Invariant mass
- $c\tau$: $L_{xy} \frac{M}{P_t(B)}$ ← 2D lifetime×c
- $\Delta\Phi$: $\phi(\vec{p}_T^{\,B}) - \phi(vtx)$
- Isolation $\frac{P_t(B)}{P_t(B) + \sum_{?R<1} P_t(trk)}$

Largest expected background: gluon splitting g→bb→μμ

Background estimation (1)

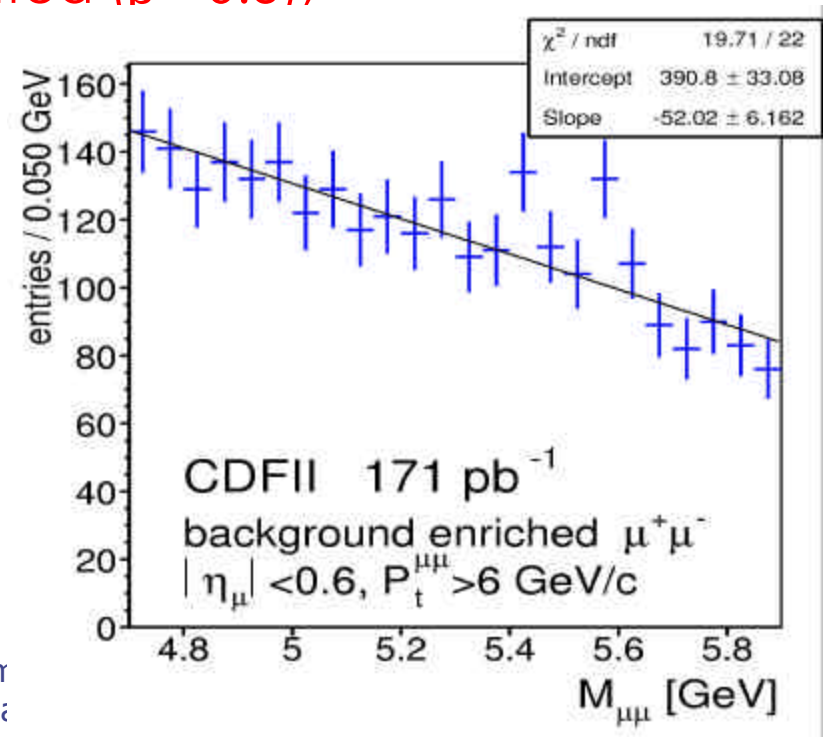
N(bgd) = N(sideband|$c\tau,\Delta\Phi$)*R(iso)*R($M_{\mu\mu}$)

- N(sideband|$c\tau,\Delta\Phi$) == sideband events passing $c\tau$ and $\Delta\Phi$ cuts
- R(iso) == fraction of bgd expected to survive an isolation cut
- R($M_{\mu\mu}$) == given N(sideband), estimate of N(signal window)

$$r_{xy} = \frac{1}{N-1} \cdot \frac{\sum (x_i - \hat{x})(y_i - \hat{y})}{s_x s_y}$$

⇨Only $c\tau$ & $\Delta\Phi$ are significantly correlated (ρ~-0.3), the rest is not ($|\rho|$~0.05) ⇒ can determine R(iso) and R($M_{\mu\mu}$) on sample w/ NO $c\tau$, $\Delta\Phi$ cuts

⇨$M_{\mu\mu}$ is linear ⇒ can use sidebands to estimate background



Background estimation (2)

⇨Method cross-checks on control samples

Cuts	N(exp)	N(obs)	$\mathcal{P}$(>=obs|exp)
loose	23 ± 3	27	20%
optimal	8 ± 1	11	17%
tight	1.2 ± 0.3	2	34%

—Sample = outside signal window

— $\mathcal{P}$(>=obs|exp) : Poisson probability

of observing >= obs events with exp expected

⇨B→hh background is negligible.

Will be sensitive to these when the limit reaches $O(10^{-9})$

Acceptance and efficiency

$$a \cdot e_{\text{total}} = a \cdot e_{\text{trig}} \cdot e_{\text{reco}} \cdot e_{\text{zvtx}} \cdot e_{\text{disVars}}$$

- α – acceptance = 6.6± 0.5%
  - so far include only muons with $|\eta|<0.6$ (CMU&CMP)
- $e_{total} \approx$ **0.52** $\cdot\, e_{disVars}$
  - take trigger and reconstruction efficiency from J/ψ data
    - +/- 10% (relative) syst due to kinematic difference with $B_{s(d)}$
  - e_{trig}=85 ± 3 %
  - $e_{reco}=(e_{COT}e_{\mu reco}e_{\mu qual}e_{SVX})^2$=71 ± 3 %
  - e_{zvtx}=95.1 ±0.1 ±0.5 % -- luminous region selection
- $e_{disVars}$ – efficiency of discriminating variables cuts, changes during optimization:
  - varied within **28-78%** for ~200 combinations of ($M_{\mu\mu}$, $c\tau$, $\Delta\Phi$, Iso).
  - cross-check the method using $B^+ \rightarrow J/\psi K^+$ data and MC (± 5% relative syst)

Optimization Results

- Optimize on ($M_{\mu\mu}$, $c\tau$, $\Delta\Phi$, Iso) to get the best expected limit

$$\langle BR(B_s \to \mu\mu)\rangle = \frac{\sum_n N(n \mid n_{bg}) \cdot P(n \mid n_{bg})}{2 \cdot a \cdot e_{total} \cdot s_{Bs} \cdot \int Ldt}$$

Poisson prob

- ($c\tau$,$\Delta\Phi$,Iso) =

  (>200 mm, <0.10 rad, >0.65)

  and mass window ± 80 MeV around

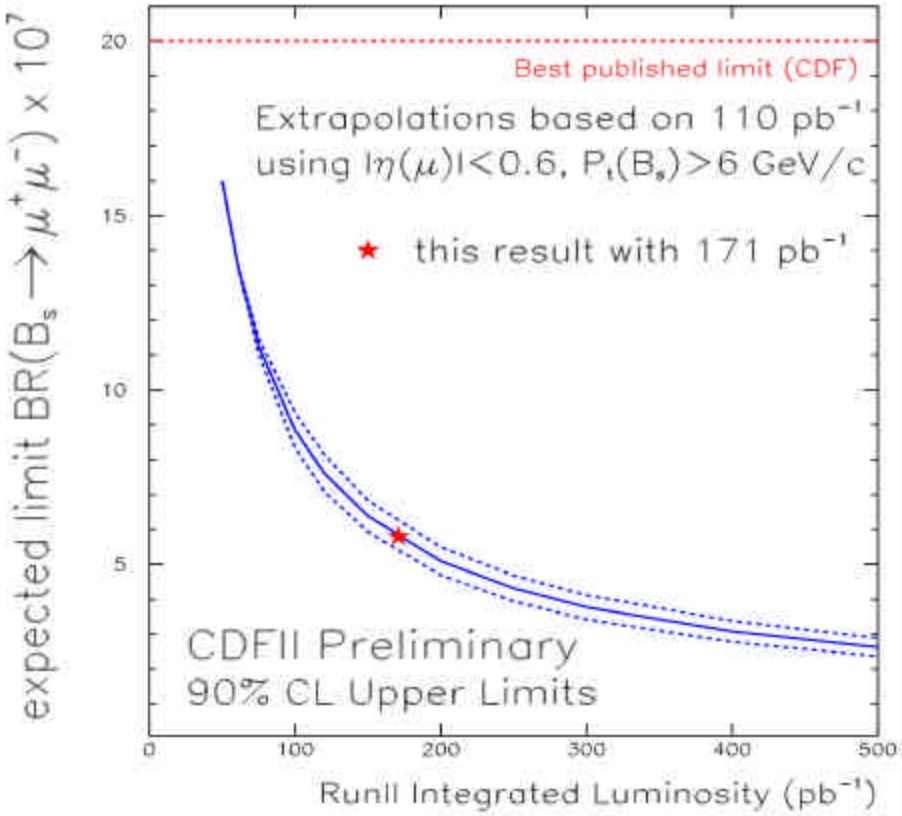
  world avg Bs(d): 5.369 GeV (5.279 GeV)

  - Bs(d): $\alpha \times \varepsilon_{total}$ = (2.0 ± 0.2)%

    ($\alpha \approx 6.6\%$, $\varepsilon_{total} \approx 30\%$)

  - Accepted bgd σ = (6 ± 2) fb
    - Expected bacground

      <Bgd> in 171pb^{-1} = 1.1 ± 0.3 events



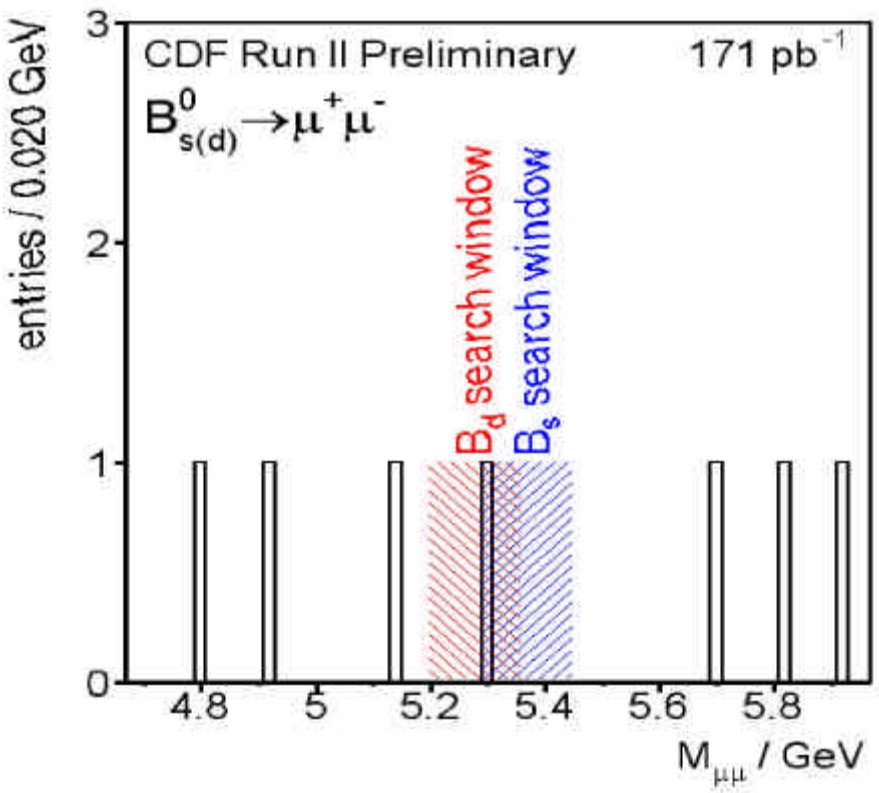
Observed limits

$BR(B_s \rightarrow \mu^+\mu^-) < 5.8\times10^{-7}$ 90% C.L. (7.5×10^{-7} 95% C.L.)

3 times better than Run I (previous world best)

$BR(B_d \rightarrow \mu^+\mu^-) < 1.5\times10^{-7}$ 90% C.L. (1.9×10^{-7} 95% C.L.)

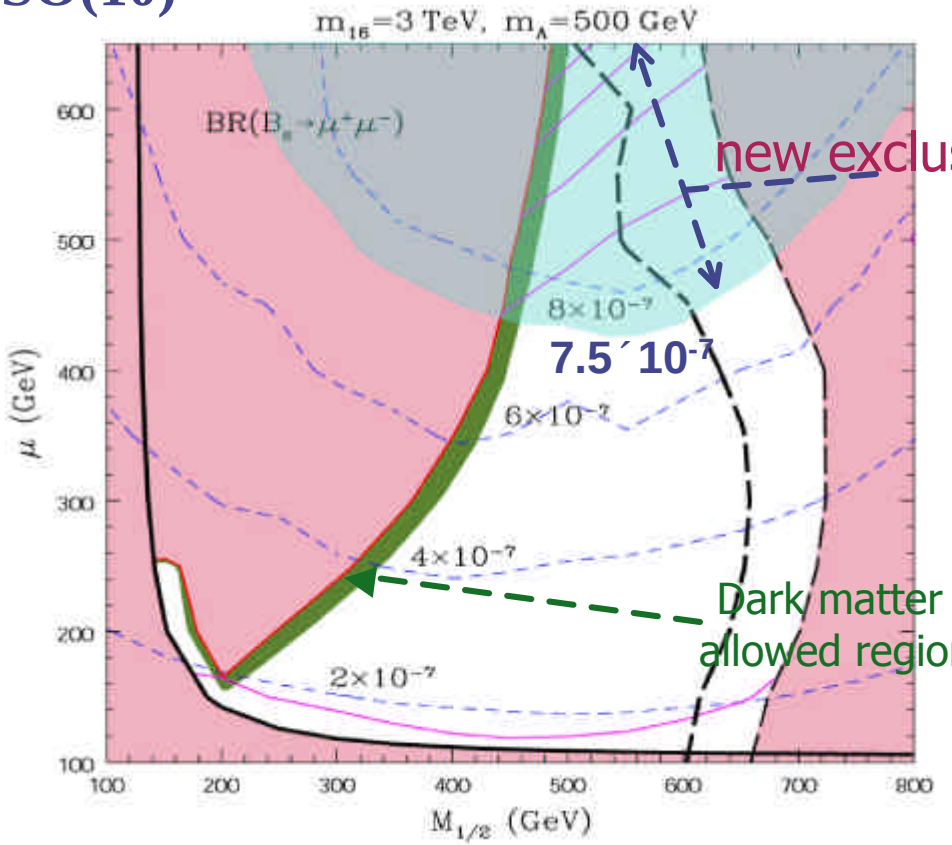
slightly better than (1.6×10^{-7} 90% C.L., just published) B-factory/Belle result



Conclusions for SUperSYmmetry (@95% C.L.)

SO(10)

R. Dermisek *et al.*, hep-ph/0304101



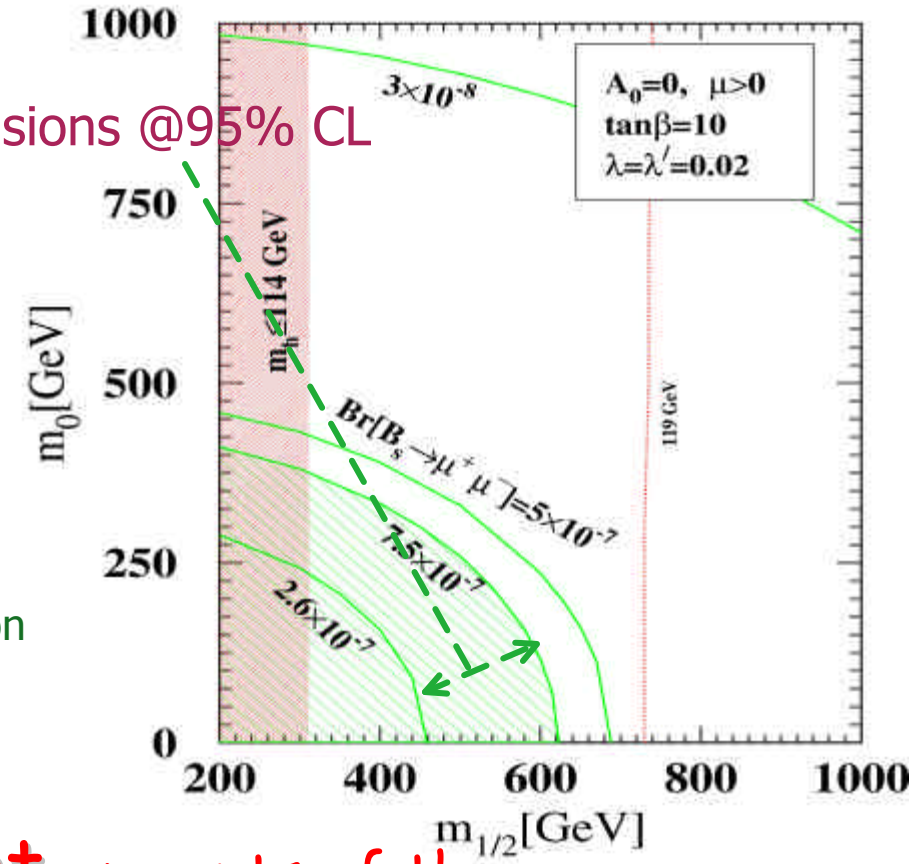
new exclusions @95% CL

7.5´10⁻⁷

Dark matter allowed region

R-parity violating

R. Arnowitt *et al.*, PLB 538 (2002) 121, new plot by B.Dutta



New limit excludes **significant** amounts of the previously allowed SUSY models parameters

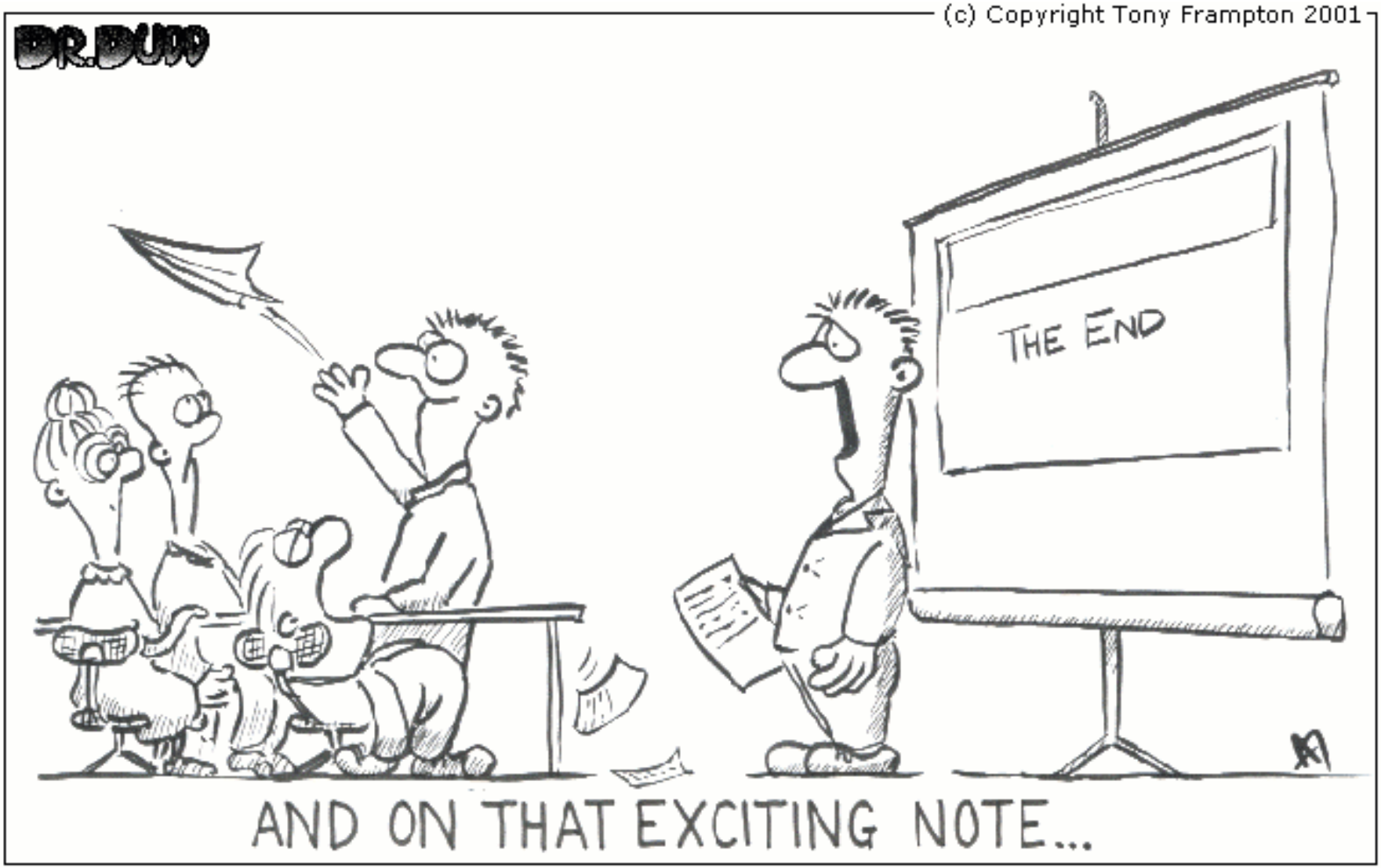
Summary

- CDF collaboration produces competitive measurements of rare B dimuon decays.

- Br($B_s \rightarrow mm$)<5.8×10^{-7} at 90% C.L.
- Br($B_d \rightarrow mm$)<1.5×10^{-7} at 90% C.L.

- This result is submitted to (and accepted by) PRL
  - hep-ex/0403032

- We expect to have Br($B_{d(s)} \rightarrow mm$) measurement significantly improving this result later this year.
  - This result does not include muons from CMX muon subdetector: another 6% in acceptance (doubling the present acceptance)
    - has larger backgrounds
  - More integrated luminosity is being collected (already have +50%)
  - Have a slightly improved reconstruction software


(c) Copyright Tony Frampton 2001
DR.DUD
THE END
AND ON THAT EXCITING NOTE...

BACKUP SLIDES

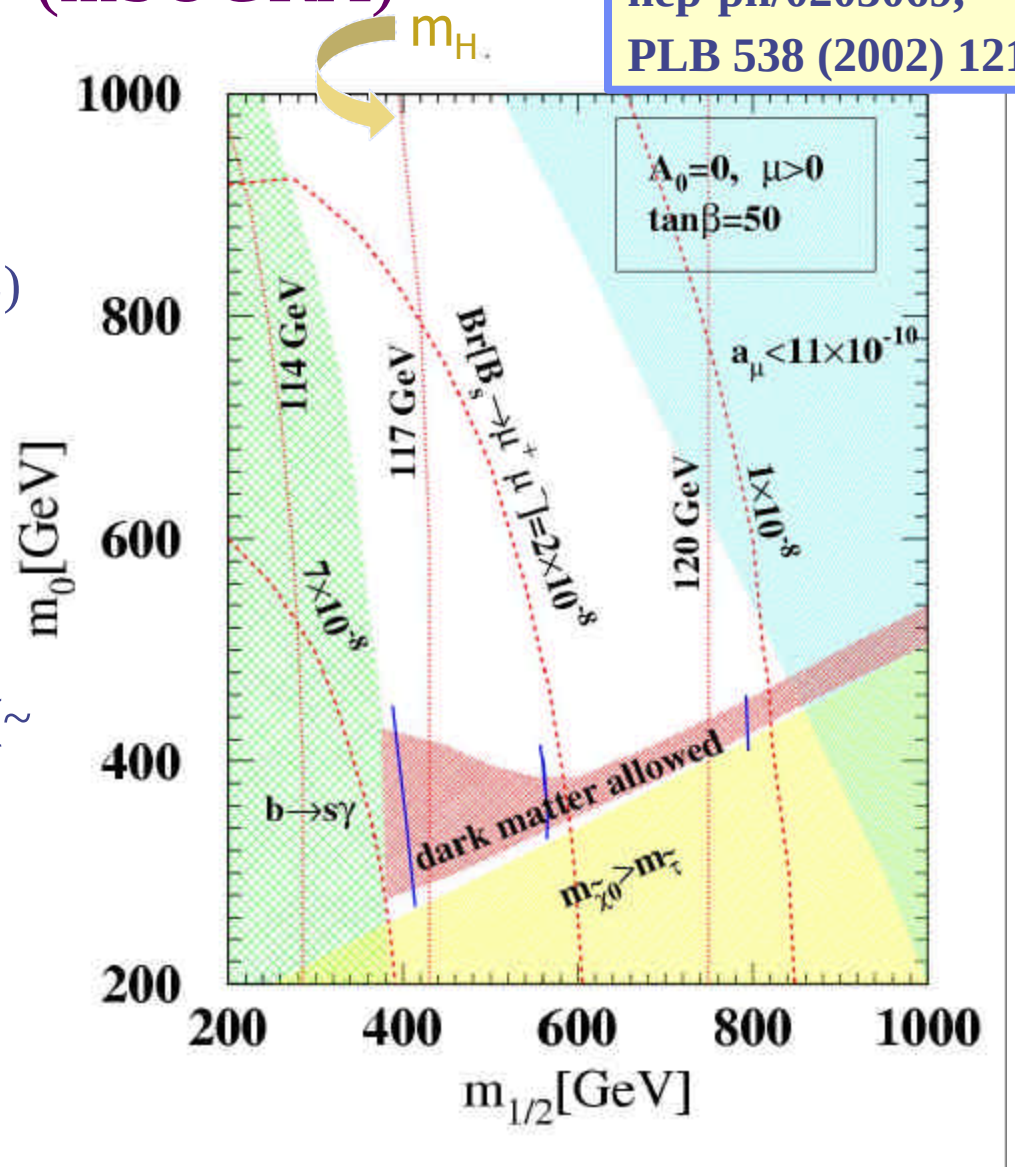
Data Samples

- OS+ : opposite-sign muon pairs, ctau > 0
  our signal sample - not used for xchecks
- OS- : opposite-sign muon pairs, ctau < 0
- SS+ : same-sign muon pairs, ctau > 0
- SS- : same-sign muon pairs, ctau < 0

Motivations: $B_s \rightarrow \mu^+\mu^-$ (mSUGRA)

R. Arnowitt *et al.*, hep-ph/0203069, PLB 538 (2002) 121

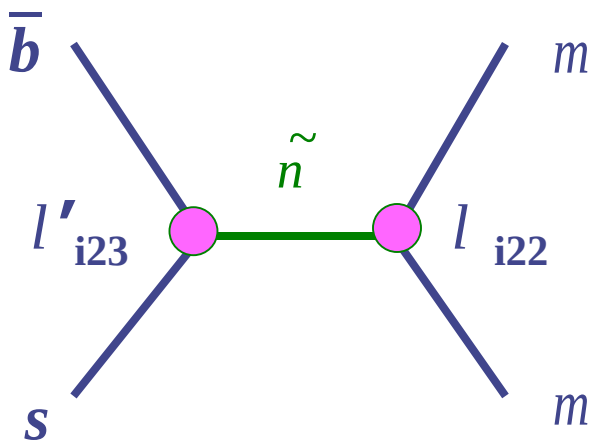
- Overlap with measured da_μ (BNL) in mSUGRA parameter space.
- Overlap with dark matter=LSP allowed region.
- Eliminate large parameter space (~ all for tanβ>40), with $Br(B_s \rightarrow \mu^+\mu^-) \sim 10^{-8}$ in Run2 (15/fb)

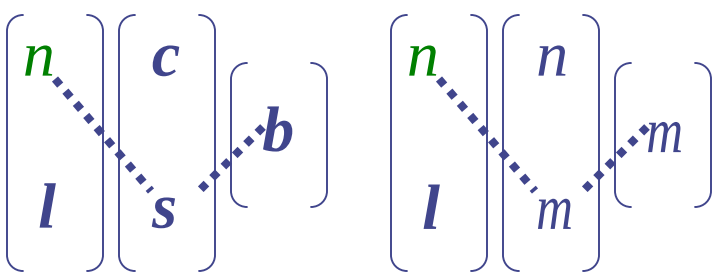


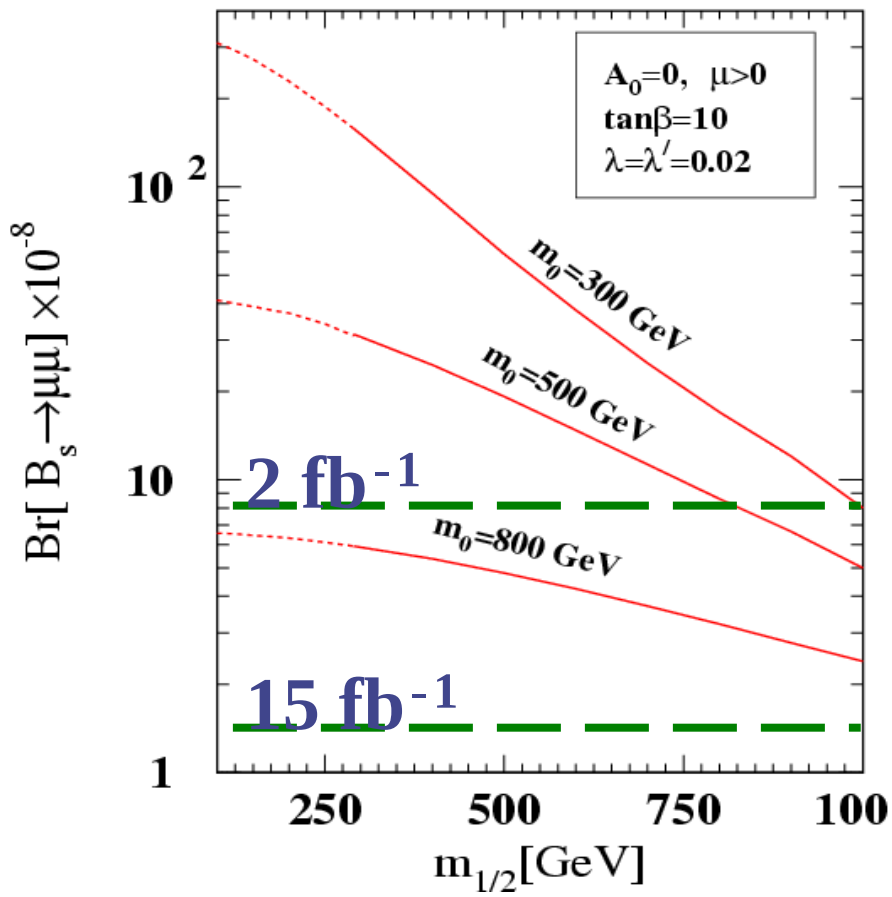
R_P Violation: *Br* vs. $m_{1/2}$

R. Arnowitt *et al.*, hep-ph/0203069, PLB 538 (2002) 121

***e.g.*, $W_{TRPV} = \lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \lambda''_{ijk} U_i D_j D_k$**

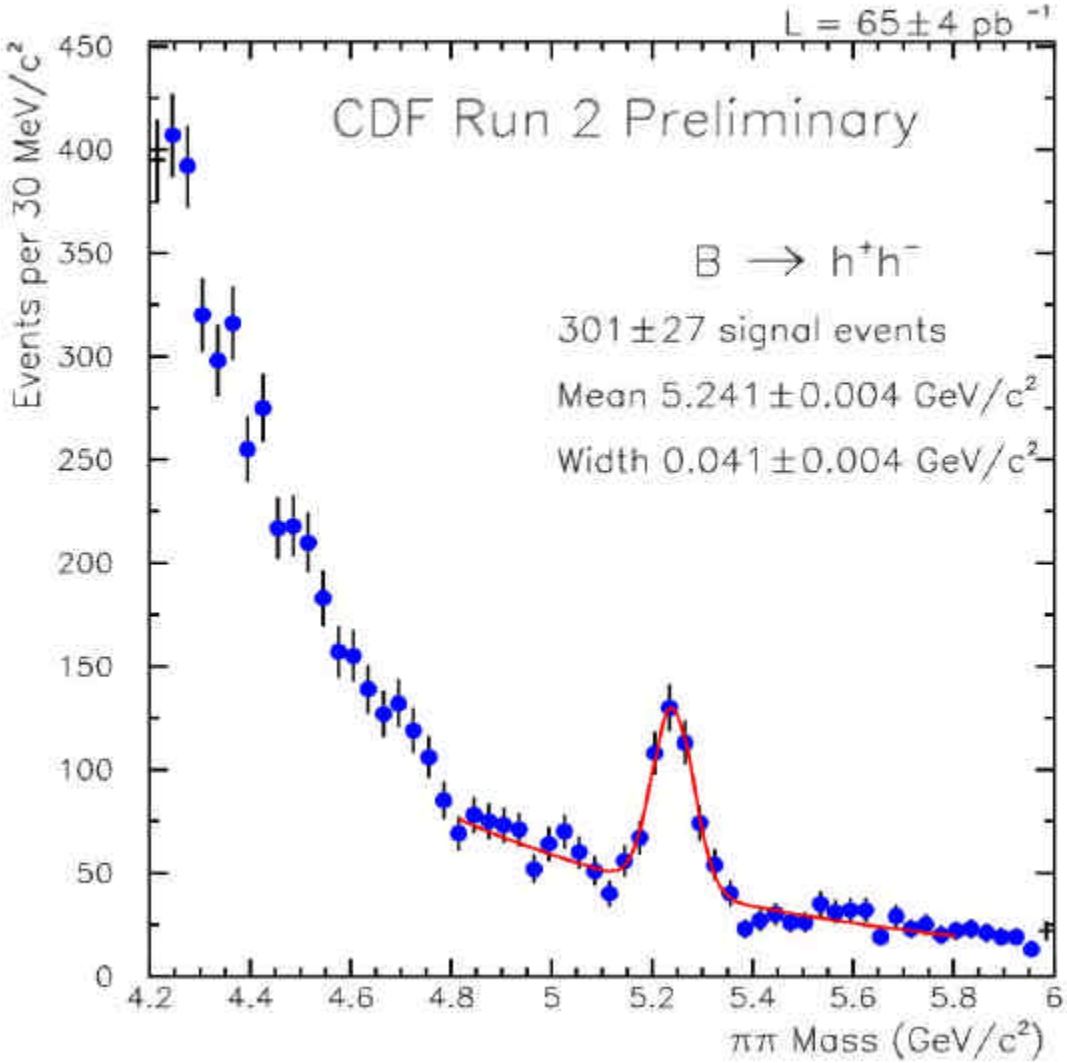






B→hh PR plot

now ~1K events with 180/pb



$B_{d(s)} \rightarrow mm$: Run I Results

CDF, PRD 57, 3811 (1998)

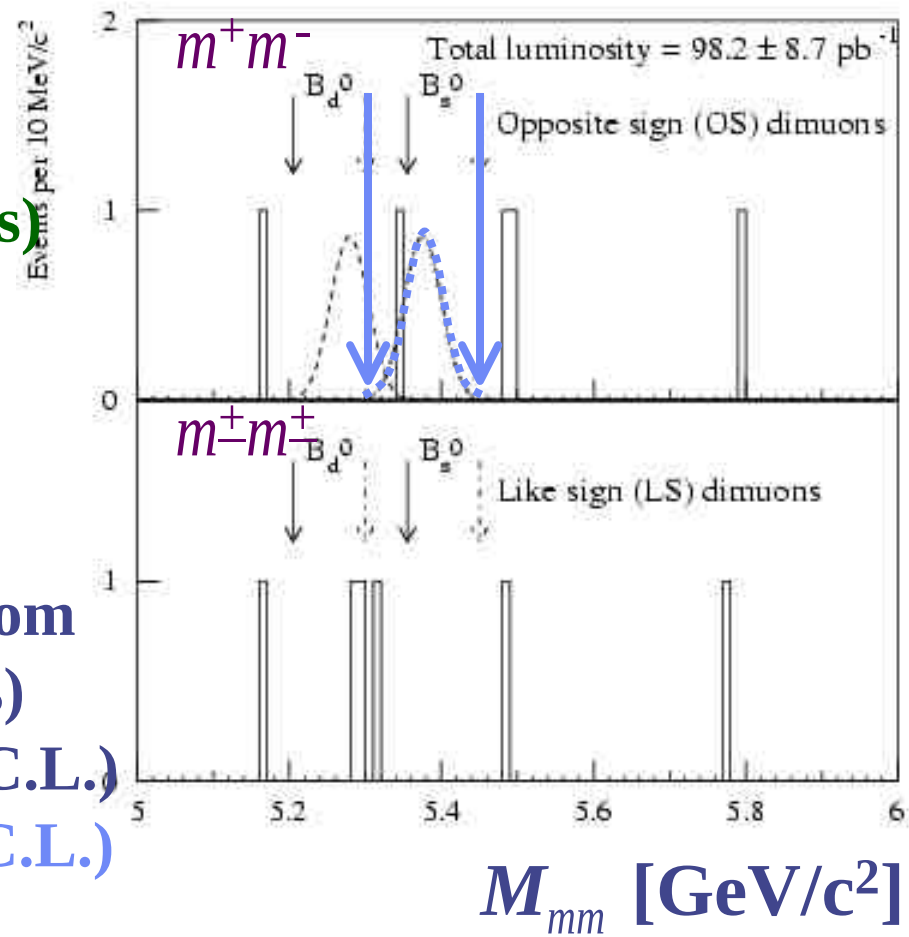
$\grave{o}\ Ldt$ = 98 pb^{-1} (~5 x 10^{12} collisions)

B_d: 5.205-5.355 GeV/c^2

B_s: 5.300-5.450 GeV/c^2

N_{obs} = 1 with 5.344 GeV/c^2

(consistent with an expectation from the Standard Model backgrounds)

$Br(B_d \rightarrow mm) < 8.6 \times 10^{-7}$ (95% C.L.)

$Br(B_s \rightarrow mm) < 2.6 \times 10^{-6}$ (95% C.L.)