B physics: new states, rare decays and branching ratios in CDF

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***For* CDF Collaboration**

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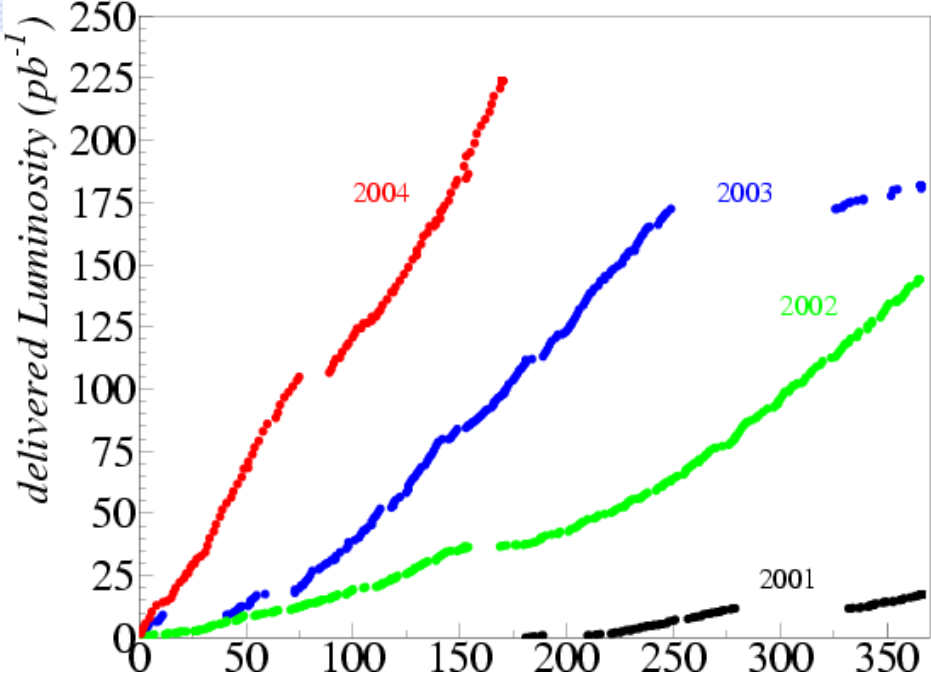
Outlines

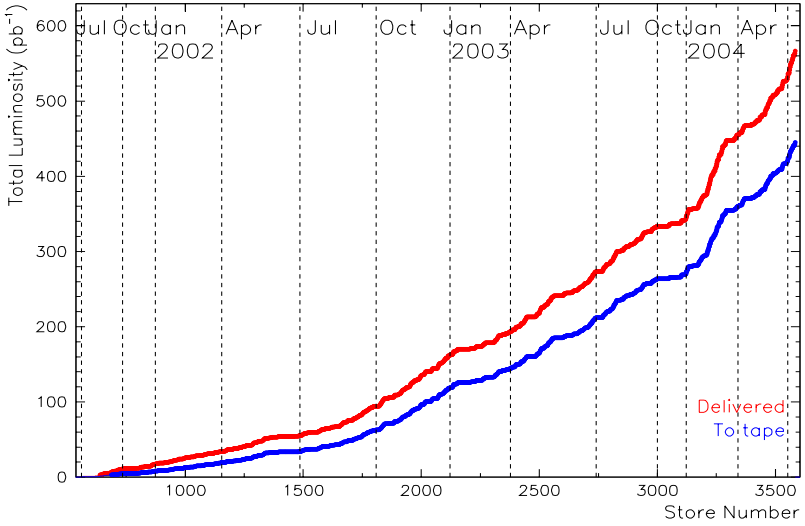
- CDF Run2
  - Detector
  - Triggers
- Searches
  - $B_{s(d)} \rightarrow \mu^+\mu^-$
  - $D^0 \rightarrow \mu^+\mu^-$
- Measurements (successful searches)
  - X(3872)
  - $B^+ \rightarrow J/\psi\ \pi^+$
  - $B_s \rightarrow \phi\phi$ and pentaquarks
    - See talks by S.D'Auria and D.Litvintsev

Tevatron performance

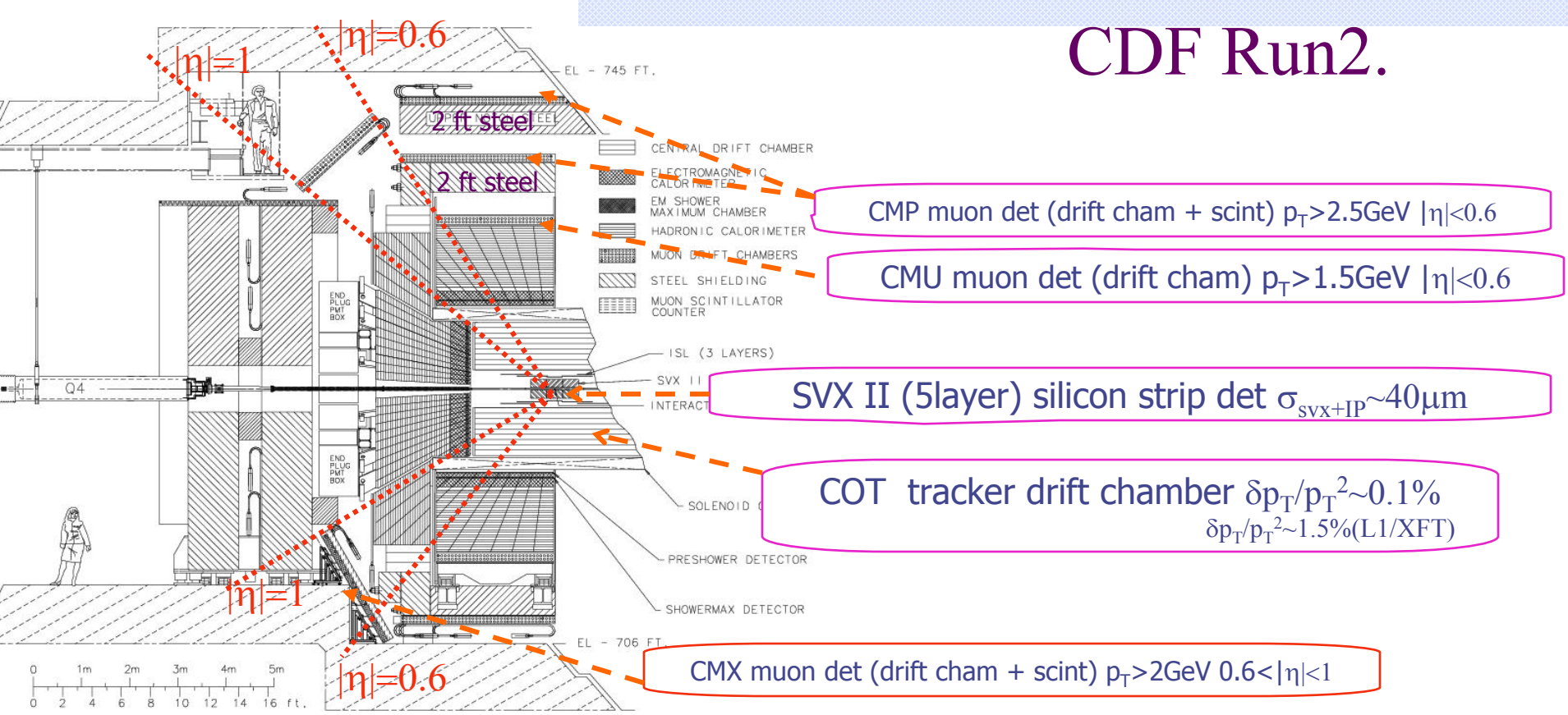


- As you know the Tevatron is working very well this year
- Record initial luminosity = $84 \times 10^{30}\ cm^{-2}s^{-1}$ ($92 \times 10^{30}\ cm^{-2}s^{-1}$ to CDF)
- Detector efficiency ~85-90%

- ~$450pb^{-1}$ on tape
- 100-200+ pb^{-1} used for analysis so far



CDF Run2.



- $\sqrt{s}$=1.96TeV σ(Inelastic)~60mb. $\mathscr{L}$~$7\times10^{31}cm^{-2}s^{-1}$ (~$400pb^{-1}$ good recorded)
  - Plan: ~$8\times10^{31}cm^{-2}s^{-1}$ (Run2a); ~$2\times10^{32}cm^{-2}s^{-1}$ (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 trigger *(bandwidth)* are B physics

Run2 vs Run1

- Better silicon coverage (×2), muon detection, improved tracking.
- Better triggers: lower track p_T, higher efficiency.

Triggers used

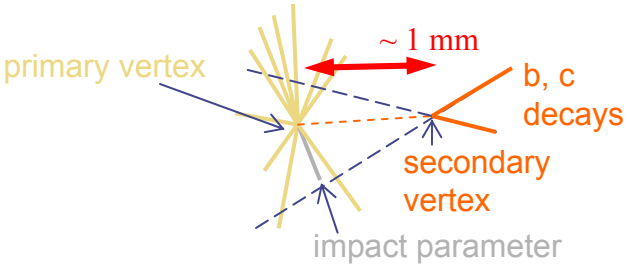
All are input to the various Level-3 triggers
That use the offline quality information

Dimuon trigger

- p_T>1.5GeV, |η|<0.6
  p_T>2GeV, 0.6<|η|<1
- p_T, ϕ, muon ID used to cut on tracks
- Used for ψ,Υ,B→μμ(+X)

Two Track Trigger

- p_T>2GeV, |η|<1
- p_T, ϕ, d_0 info used to cut on 2 tracks
- Used for: B,D→hadrons ; D→μμ

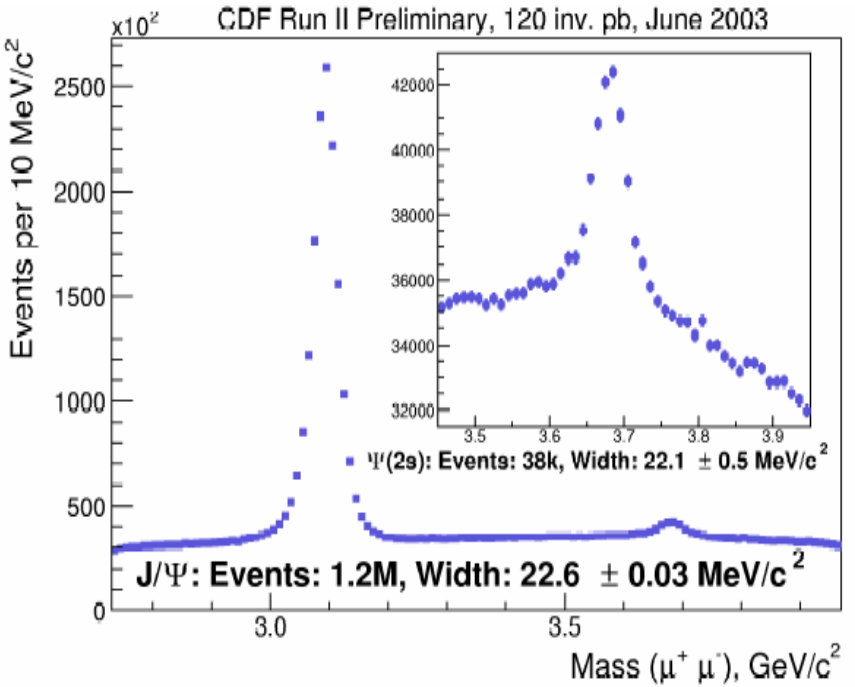


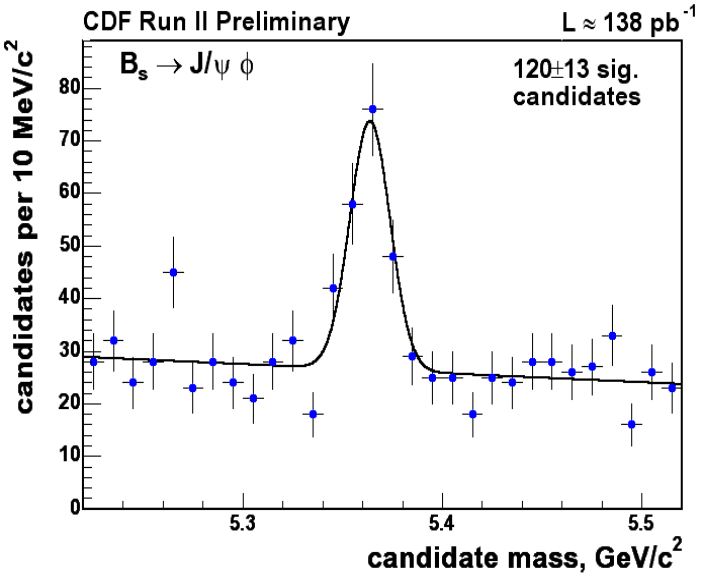
Semileptonic trigger

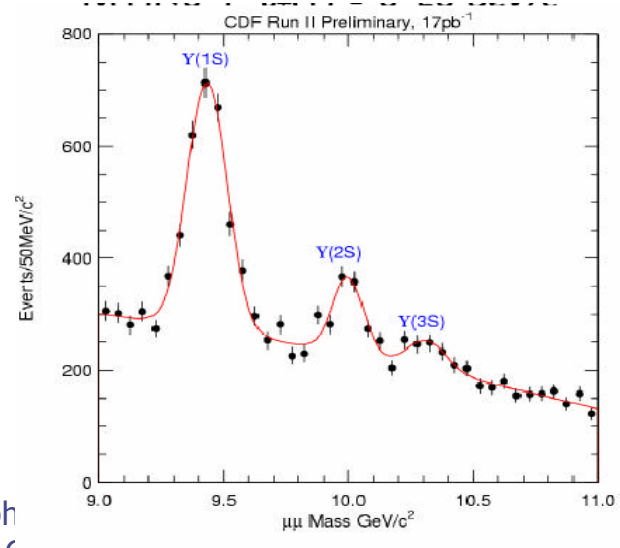
- p_T, ϕ, d_0, muon ID used to cut on tracks
- Used for ψ,D,B→μ(+X)
- *no results presented in this talk*

Triggers used

- Dimuon trigger
  - p_T>1.5GeV, |η|<0.6
    p_T>2GeV, 0.6<|η|<1
  - p_T, ϕ, muon ID used to cut on tracks
  - Used for ψ,Y,B→μμ(+X)

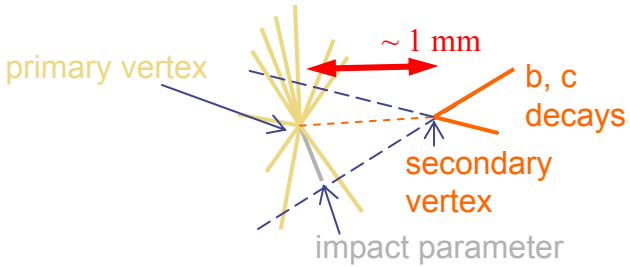


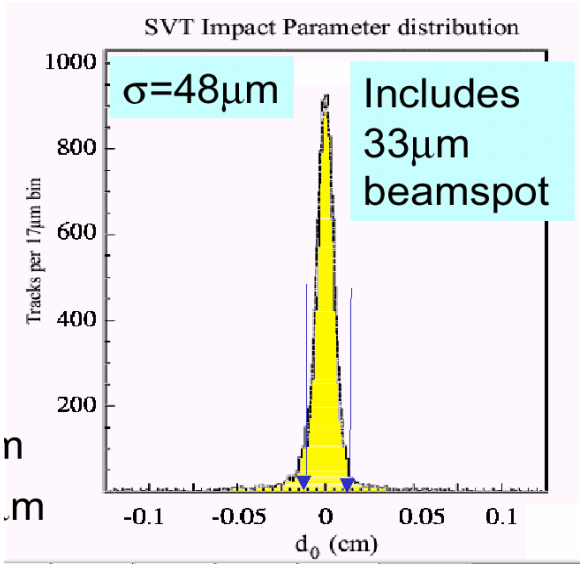


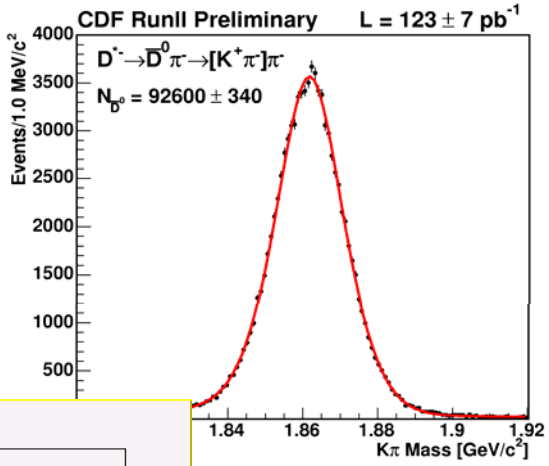


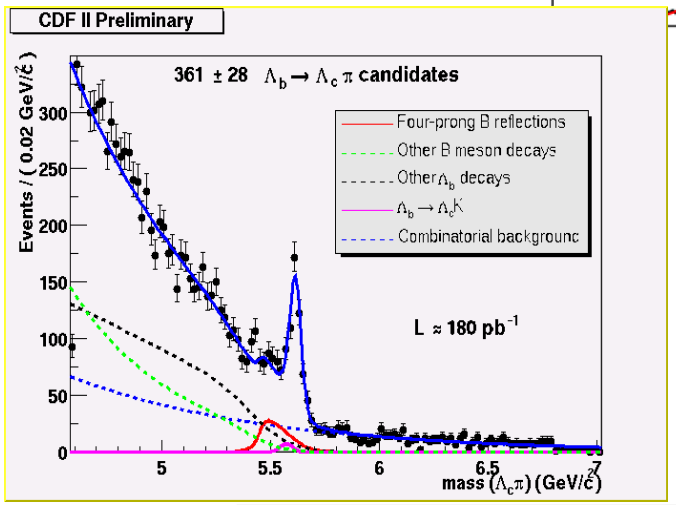
Triggers used

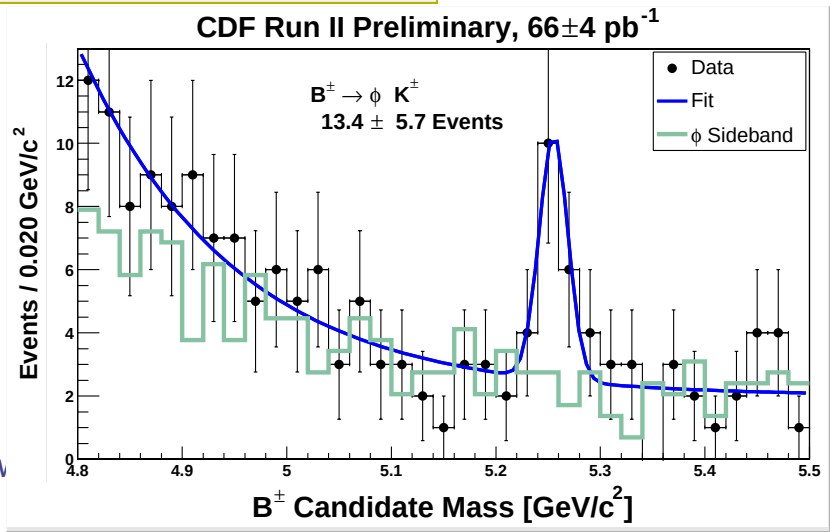
- Two Track Trigger
  - p_T>2GeV, |η|<1
  - p_T, ϕ, d_0 info used to cut on 2 tracks @L2
  - Used for: B,D→hadrons ; D→μμ





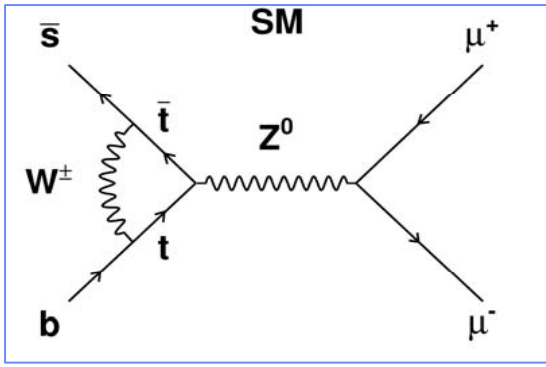


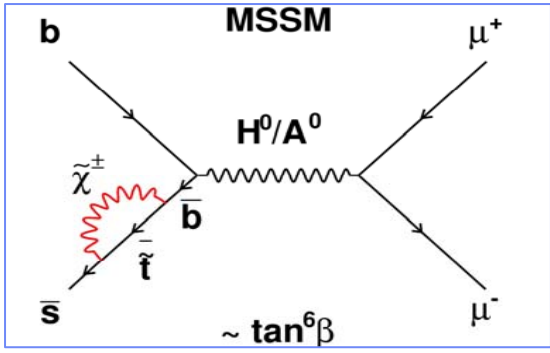




B(D)→μμ: Theoretical motivations. Current limits.

- 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)
  - $Br_{SM}(D^0 \to \mu^+\mu^-) \sim 3 * 10^{-13}$ (GIM suppressed)
- 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.
  - $Br_{exp}(D^0 \to \mu^+\mu^-) < 4.1(4.2) * 10^{-6}$ 90% C.L. BEATRICE(E771)





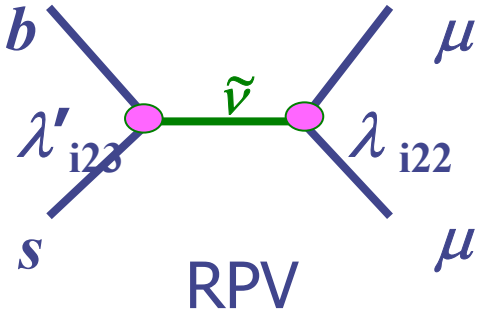
mSUGRA,SO(10)

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

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

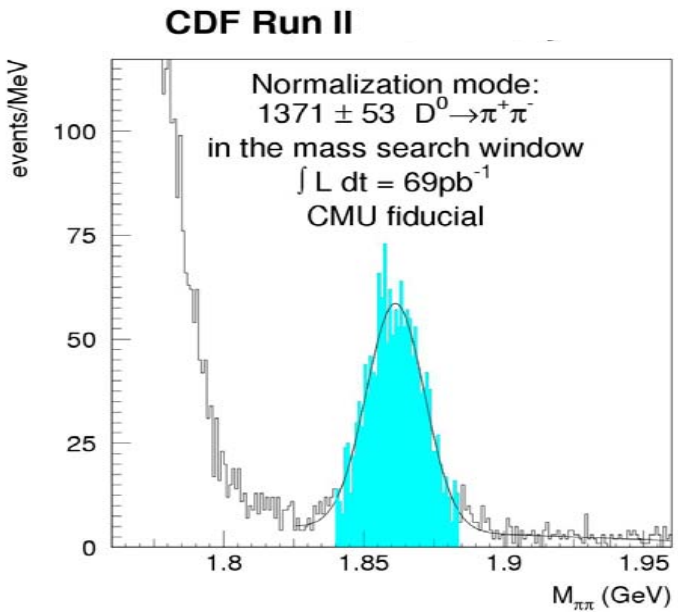
- Can be seen in Run2 (esp. $B_s \to \mu\mu$)

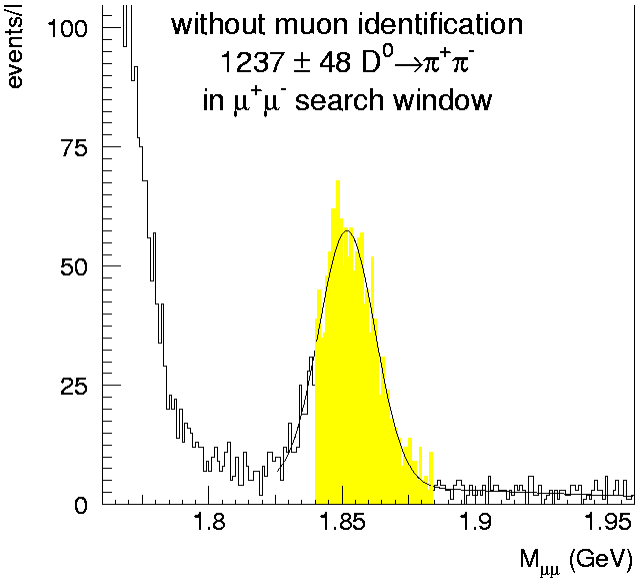
- Other models enhance less. E.g., universal extra dimensions. Up to +70% for $B_s \to \mu^+\mu^-$



RPV

$D^0 \rightarrow \mu\mu$ search





- Use $D^{*\pm} \rightarrow D_0\pi^\pm$ tagged events
- Use $D_0 \rightarrow \pi^+\pi^-$ as a normalization mode.
  - Blind from μID in $1.840 < m_{\mu\mu} < 1.882$ GeV
- Cuts:
  - $|d_0(\mu,\pi)| > 120\mu m$, $|d_{xy}(D_0)| < 150\mu m$
  - $\Delta\varphi(\mu\mu) > 0.085$
- Background:
  - combinatorial (from right sideband) – expect 1.5 ± 0.7
  - misidentification (punch-through/decay) – expect $N(D_0 \rightarrow \pi^+\pi^-) \times P(\text{misID})^2 \approx 0.3 \pm 0.1$

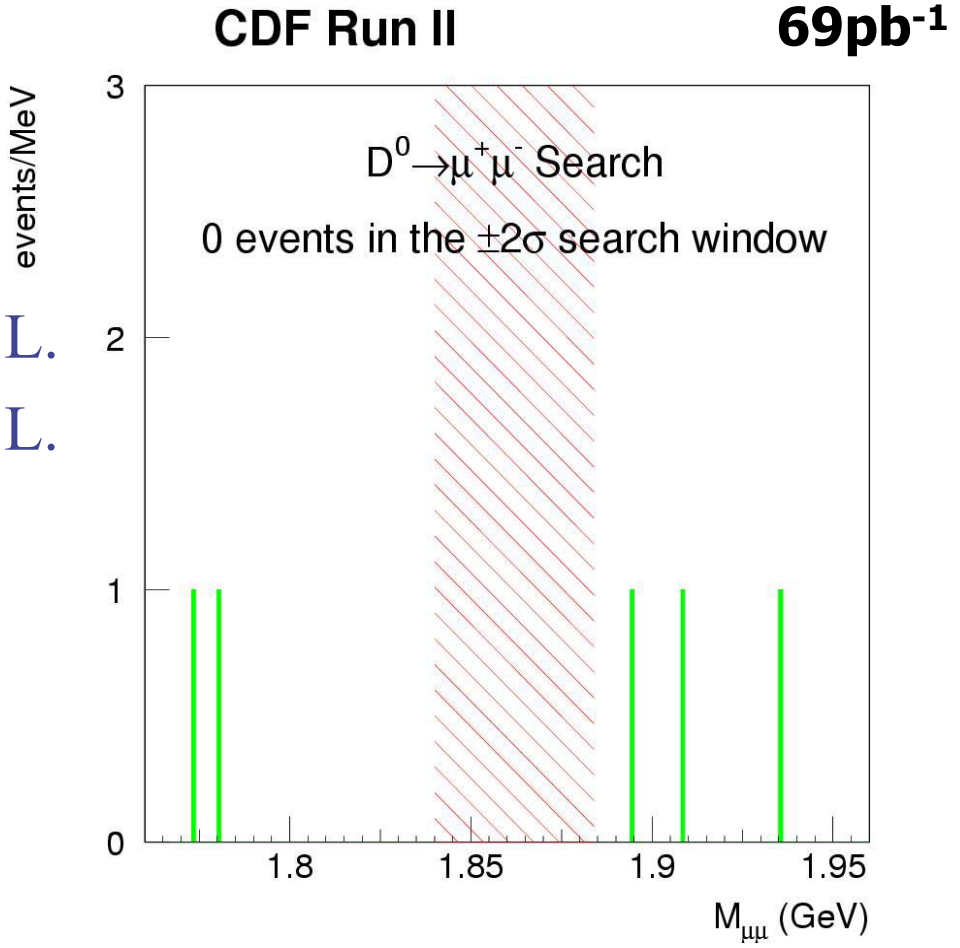
$$Br(D^0 \rightarrow \mu\mu) \leq \frac{N_{CL}(D^0 \rightarrow \mu\mu)}{N(D^0 \rightarrow \pi\pi)} \frac{\varepsilon(D^0 \rightarrow \pi\pi)}{\varepsilon(D^0 \rightarrow \mu\mu)} Br(D^0 \rightarrow \pi\pi)$$

≈ 1.012 $\approx 1.43 \cdot 10^{-3}$

$D^0 \rightarrow \mu\mu$ search

- B($D^0 \rightarrow \mu\mu$)<2.4×10^{-6} @ 90% C.L.
- B($D^0 \rightarrow \mu\mu$)<3.1×10^{-6} @ 95% C.L.

- This result improves on the previous limits by ~×2
  (4.1×10^{-6} from BEATRICE, and 4.2×10^{-6} from E771 at 90% C.L.)



Br($B_{s(d)}$→μ+μ-) measurement.

$$BR(B_s \to \mu\mu) \le \frac{N_{CL}(n_{obs}, n_{bg})}{2 \cdot \alpha \cdot \varepsilon_{total} \cdot \sigma_{Bs} \cdot \int Ldt}$$

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

171pb-1 or 10 trillion collisions

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)

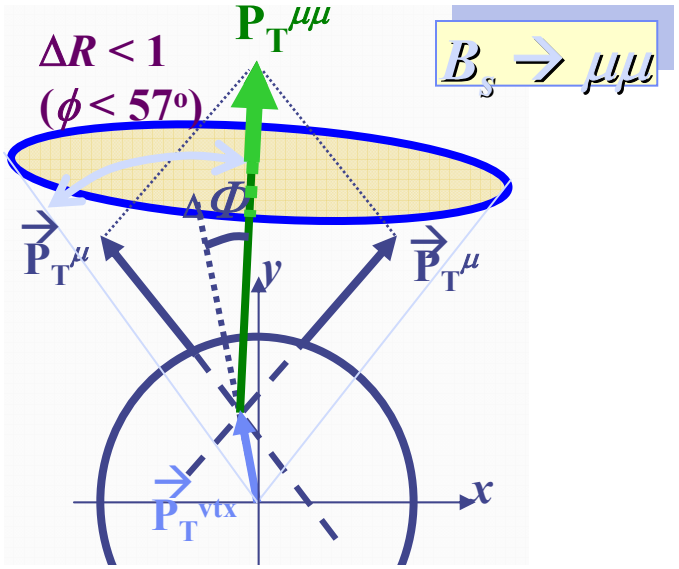
25% Run1

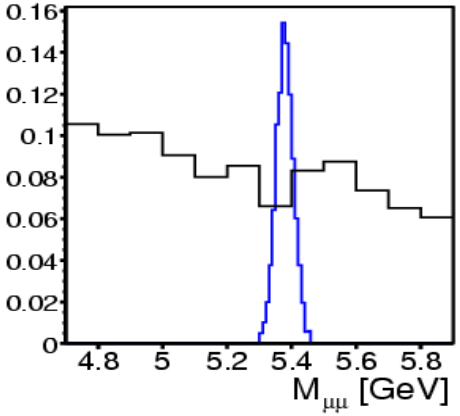
Dimuon trigger and p_T>6GeV
baseline sample: 2940 events

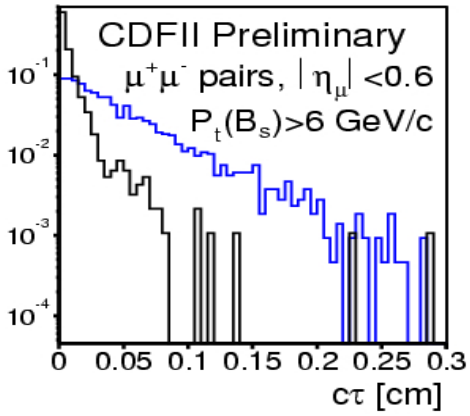
- Expect to detect at most few events that might only look like $B_{s(d)}$→μ+μ–
- SM predicts 0 events ⇒ really a "search"
  - Don't look at the data signal region (blind search)
  - Signal inside 5.169<$M_{\mu\mu}$<5.469 GeV/c^2 (±3σ window)
- demonstrate understanding of background events
- accurately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

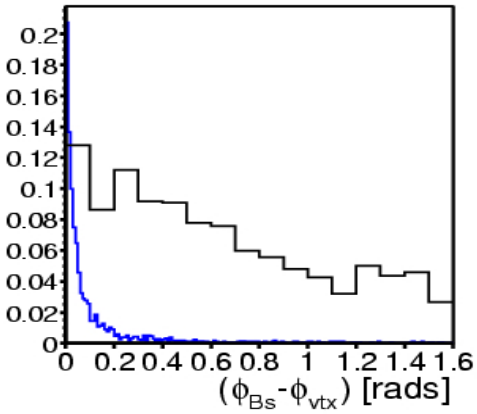
Signal & Background

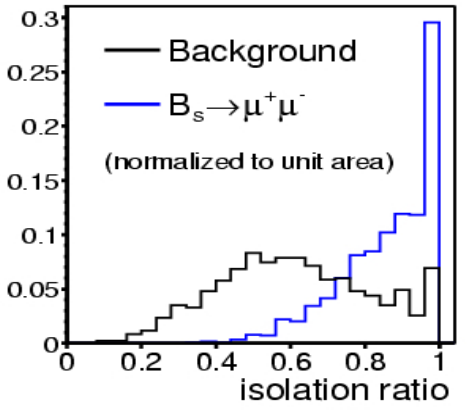
☞Need to select discriminating variables that leave most of the signal and remove most of the background.











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 $\dfrac{P_t(B)}{P_t(B) + \sum_{\Delta R<1} P_t(trk)}$

Largest expected background: gluon splitting $g \to bb \to \mu\mu$

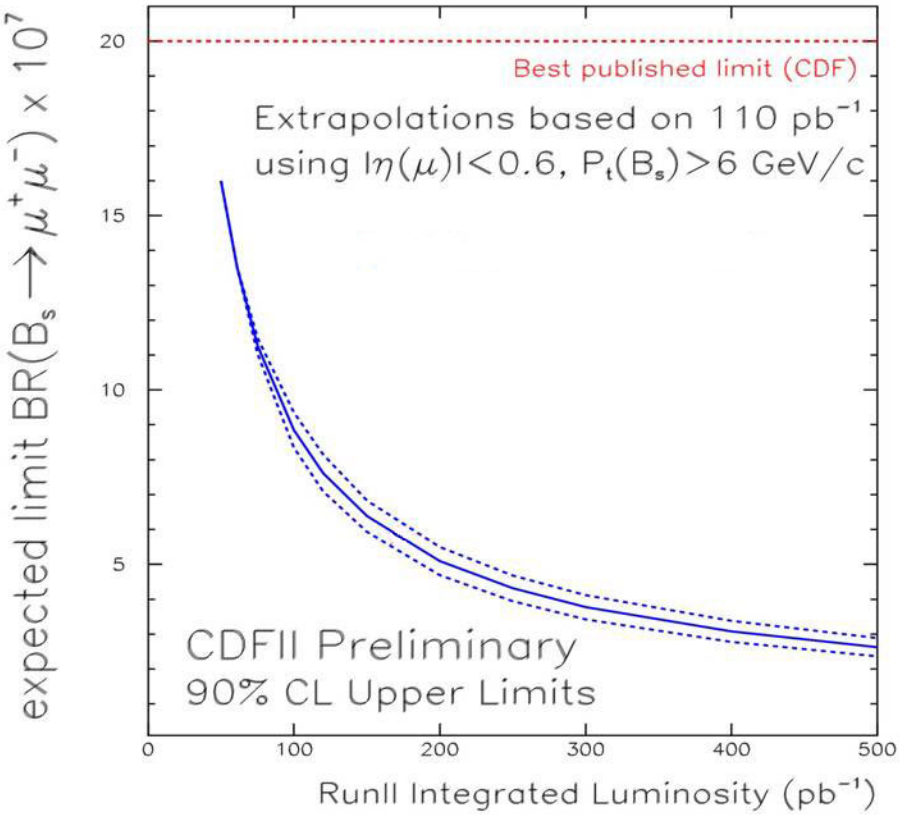
Optimization Results

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

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

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): $\alpha \times \varepsilon_{total} = (2.0 \pm 0.2)\%$
    ($\alpha \approx 6.6\%$, $\varepsilon_{total} \approx 30\%$)
  - Accepted bgd $\sigma = (6 \pm 2)$ fb
    - Expected bacground
      <Bgd> in 171pb^{-1} = 1.1 ± 0.3 events



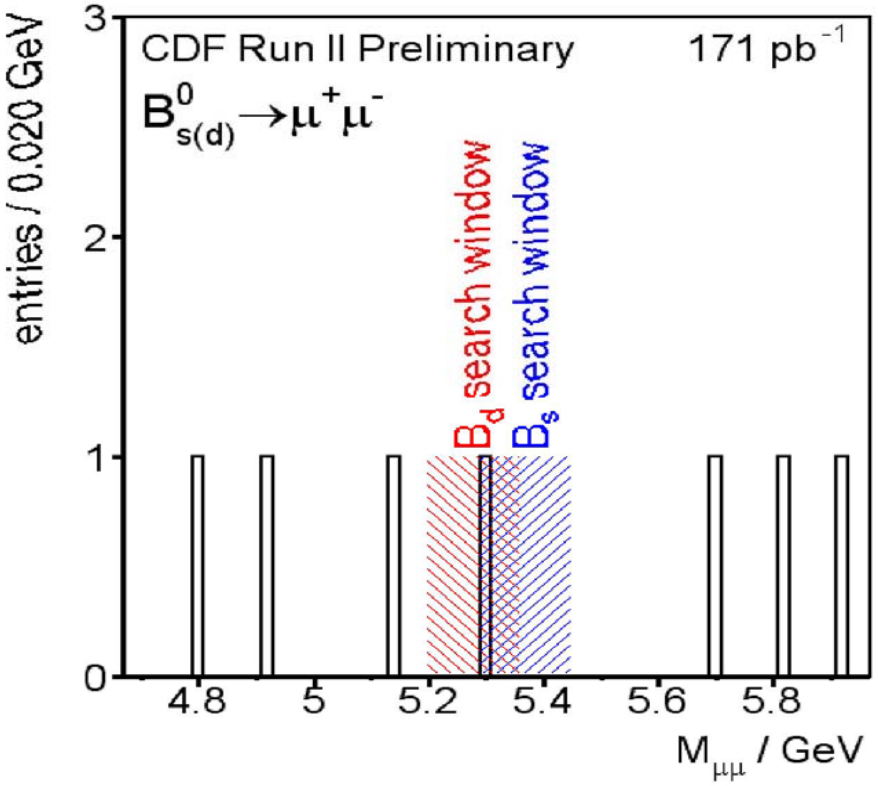
Observed limits

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

3 times better than Run I (previous world best)

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

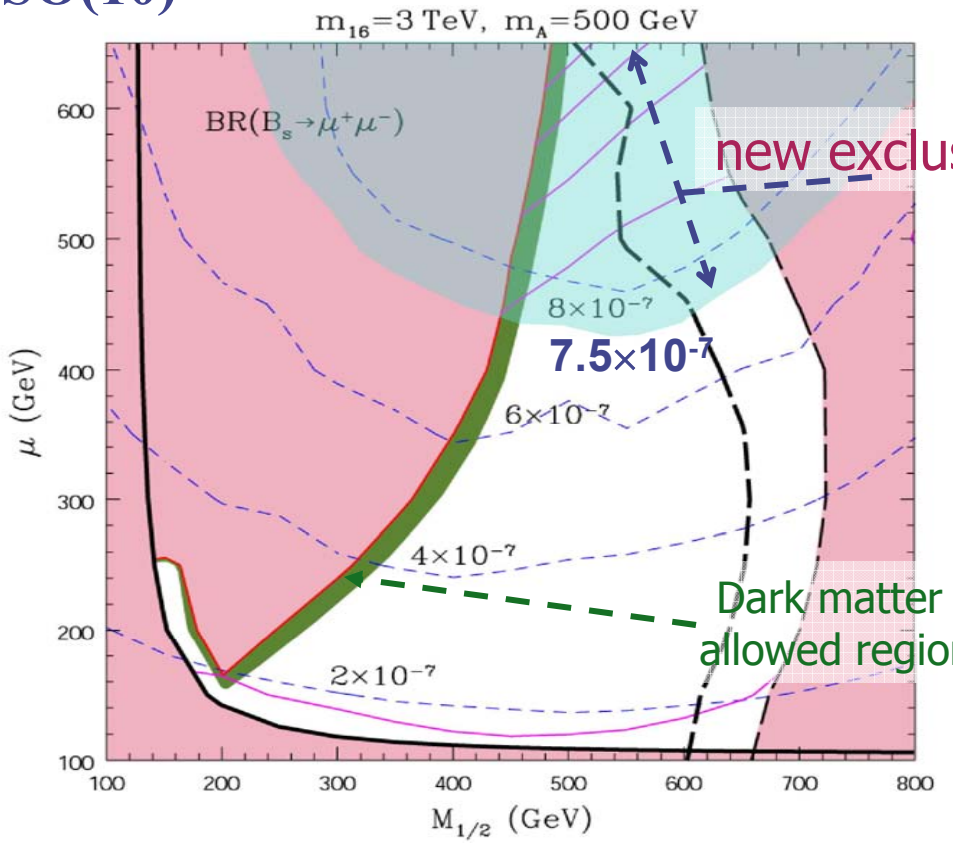
slightly better than (1.6×10^{-7} 90% C.L., just published)
B-factory/Belle result



→ for SUperSYmmetry (@95% C.L.)

SO(10)

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

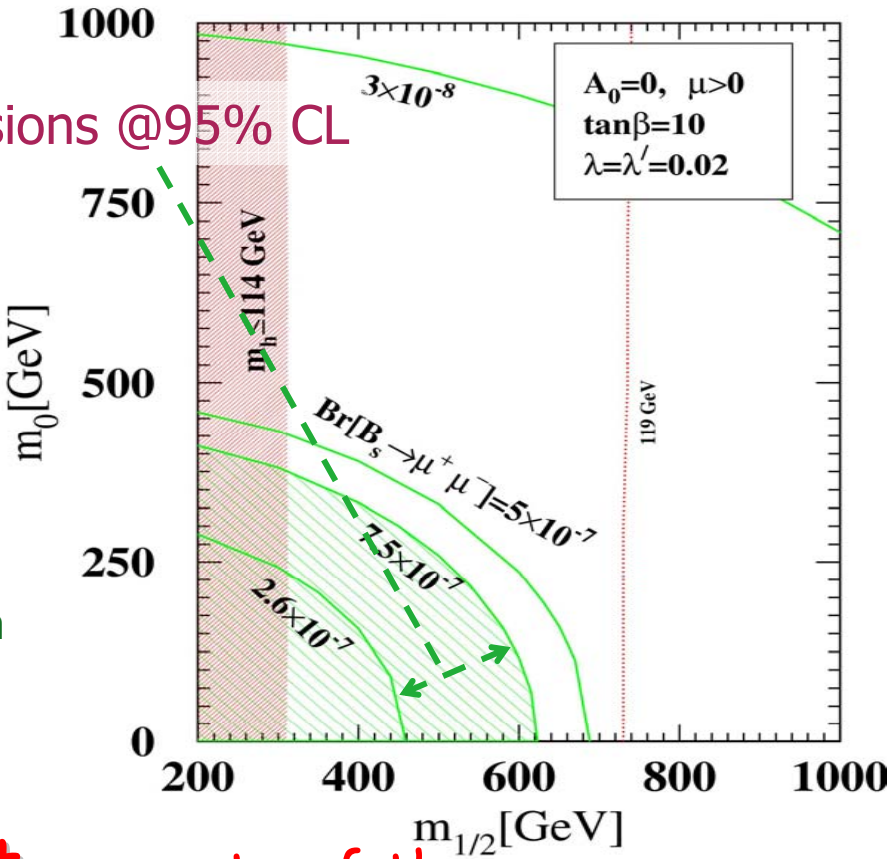


new exclusions @95% CL

Dark matter allowed region

R-parity violating

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



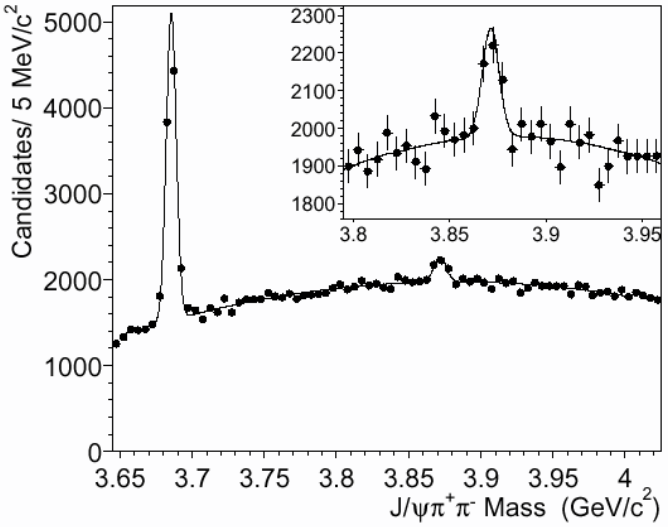
New limit excludes **significant** amounts of the previously allowed SUSY models parameters (more to go)

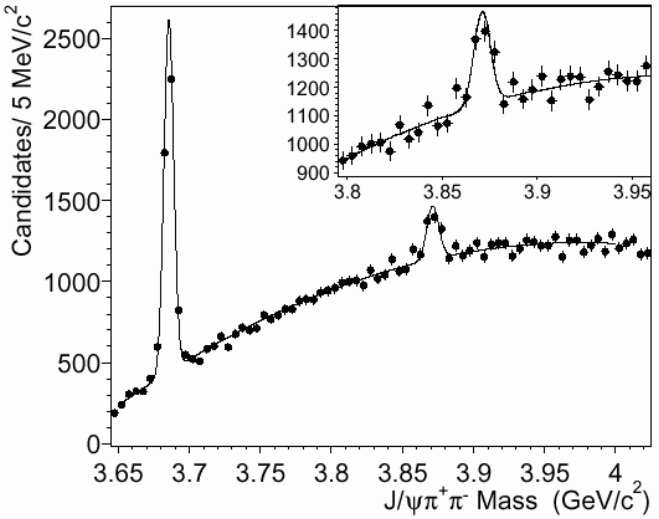
Spectroscopy – Exotic States X(3872)

- New narrow state observed first by Belle in decay modes $J/\psi\pi^+\pi^-$
- Charmonium state not expected near mass peak.
- D* Dbar deuteron-like molecule ?
- CDF confirms X in 220pb^{-1}
- Preference for M(π π) > 500MeV
- 670±90 candidates, sign.~ 12σ
- Mass scale using ψ(2S) peak

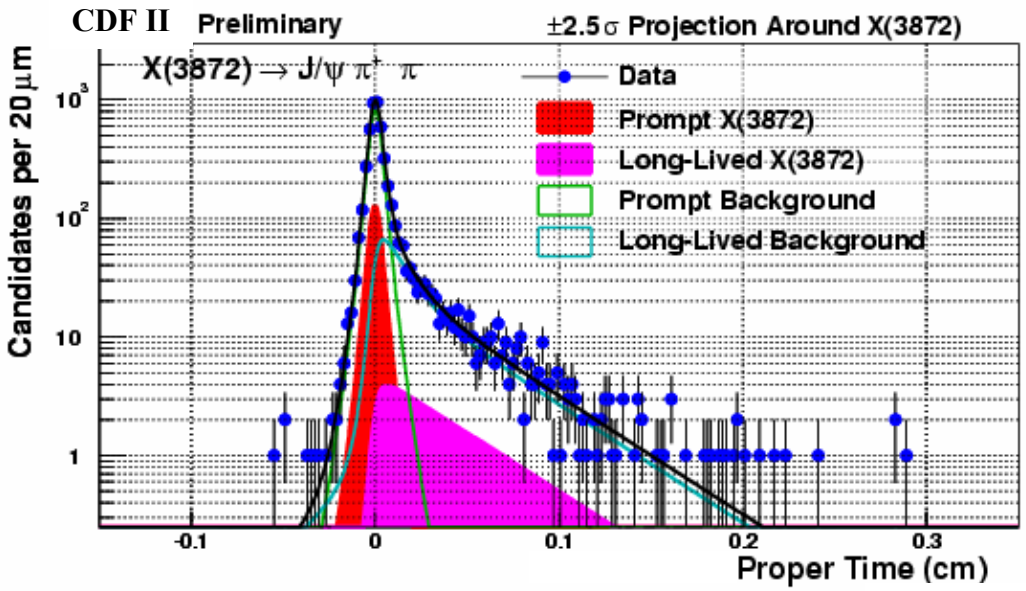
CDF: $m_{X(3870)} = (3871.3 \pm 0.7 \pm 0.4)\ \mathrm{MeV}/c^2$

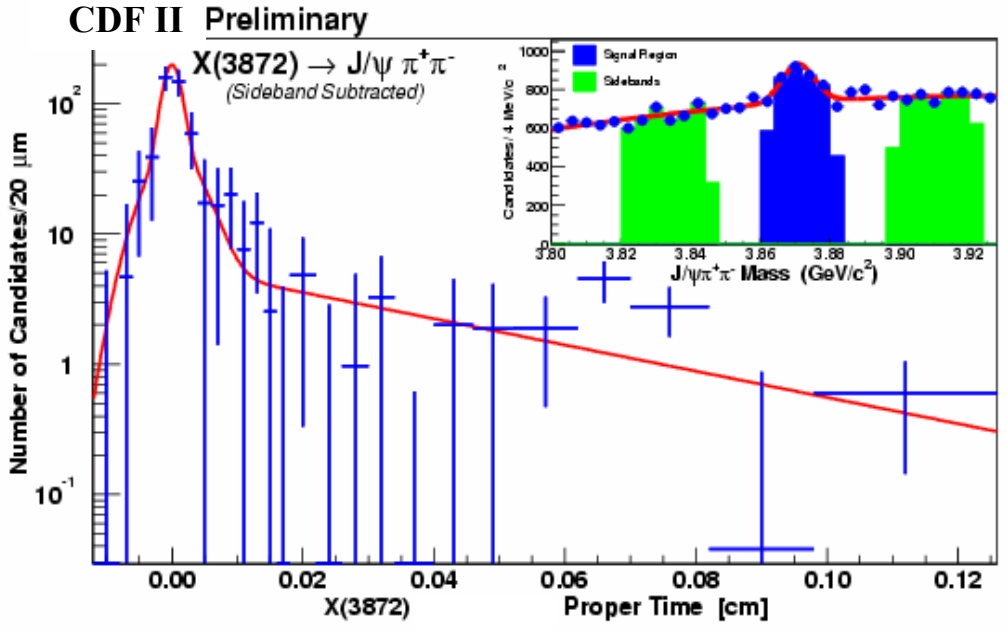
Belle: $m_{X(3870)} = (3872.0 \pm 0.6 \pm 0.5)\ \mathrm{MeV}/c^2$





X(3872): Long-lived fraction

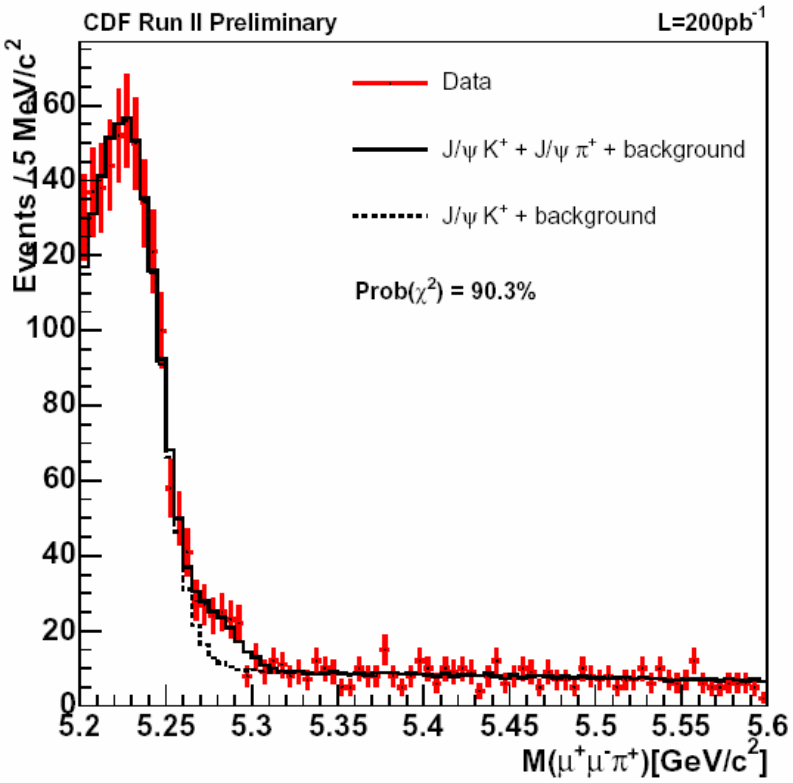




- Long-lived fraction:
  - $F_{X(3872)} = 16.1 \pm 4.9 \pm 2.0\ \%$
  - *cf* $F_{\psi(2S)} = 28.3 \pm 1.0 \pm 0.7\ \%$

S. Krutelyov

$B \rightarrow J/\psi\ \pi^+$



- Cabibbo-suppressed decay $B^+ \rightarrow J/\psi\pi^+$
  - Br Expected to be 5% relative to $Br(B^+ \rightarrow J/\psi K^+)$
  - $Br(B^+ \rightarrow J/\psi\pi^+)/Br(B^+ \rightarrow J/\psi K^+)=4.2 \pm 0.7\%$ PDG02
- Signal selection
  - $p_T(B^+)>6.5GeV$, $p_T(K^+)>2GeV$, $L_{xy}>200\mu m$

Fitting Result

parameter	value
Mass(B^+)	5.279±0.0003
scale	1.60±0.04
slope	−2.65±0.95
f_{sig}	0.74±0.01
r_{obs}	0.045±0.008
N($J/\psi K^+$)	1986.1±35.3
N($J/\psi\pi^+$)	89.7±15.4
ε_{rel}	0.991±0.008

$$\frac{Br(B^+ \rightarrow J/\psi\pi^+)}{Br(B^+ \rightarrow J/\psi K^+)} = (4.5 \pm 0.8(stat.) \pm 0.3(syst.))\%$$

Summary

- Great physics results are coming in from CDF

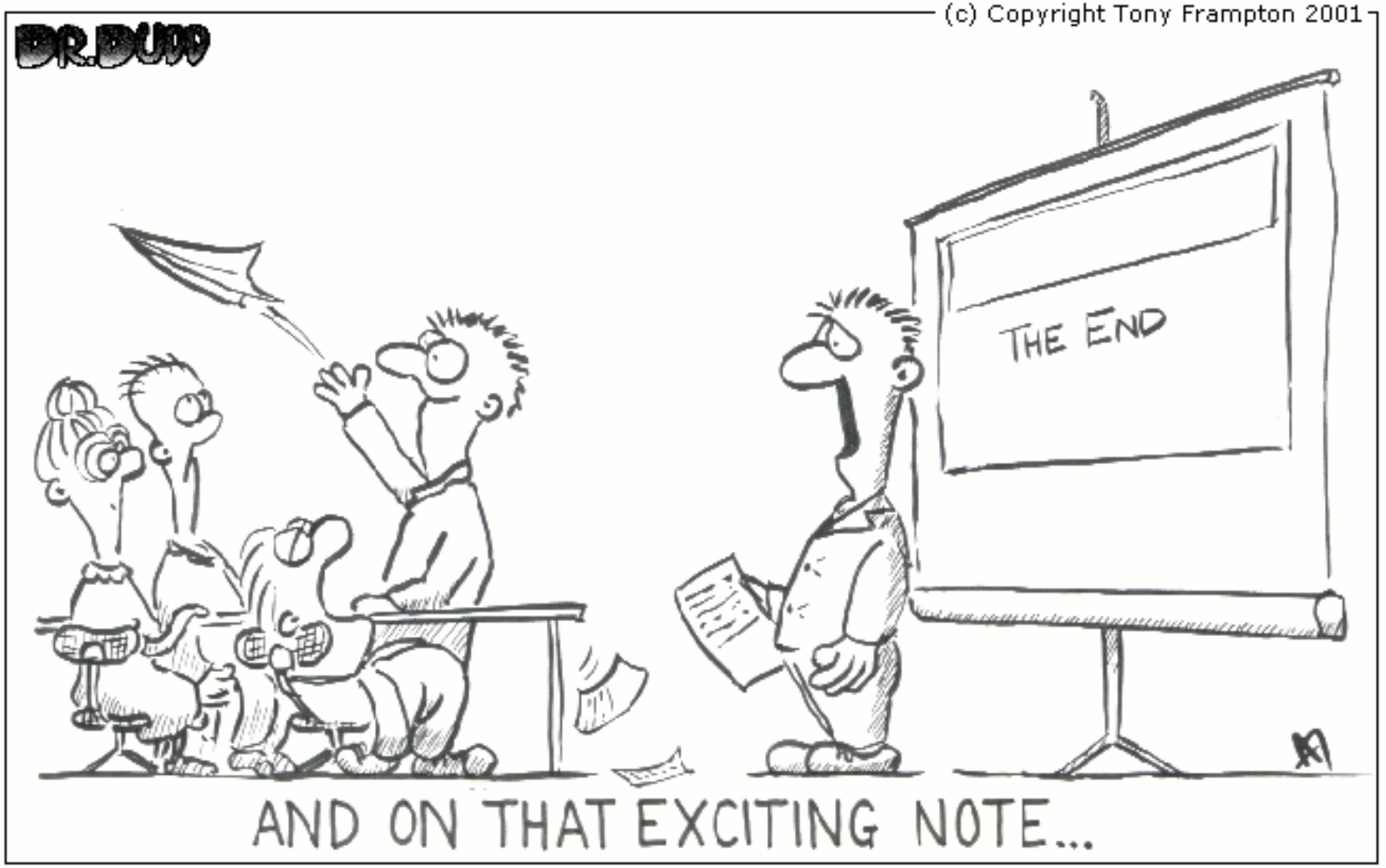
- Br($B_s \rightarrow \mu\mu$)<5.8×10^{-7} at 90% C.L.
- Br($B_d \rightarrow \mu\mu$)<1.5×10^{-7} at 90% C.L.
- Br($D \rightarrow \mu\mu$)<2.4×10^{-6} at 90% C.L.

accepted/published by PRL

- X(3872) confirmation

- Long-lived fraction $F_{X(3872)}$=16.1 ± 4.9 ± 2.0 %

- $$\frac{Br(B^+ \rightarrow J/\psi\pi^+)}{Br(B^+ \rightarrow J/\psi K^+)} = (4.5 \pm 0.8(stat.) \pm 0.3(syst.))\%$$


(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

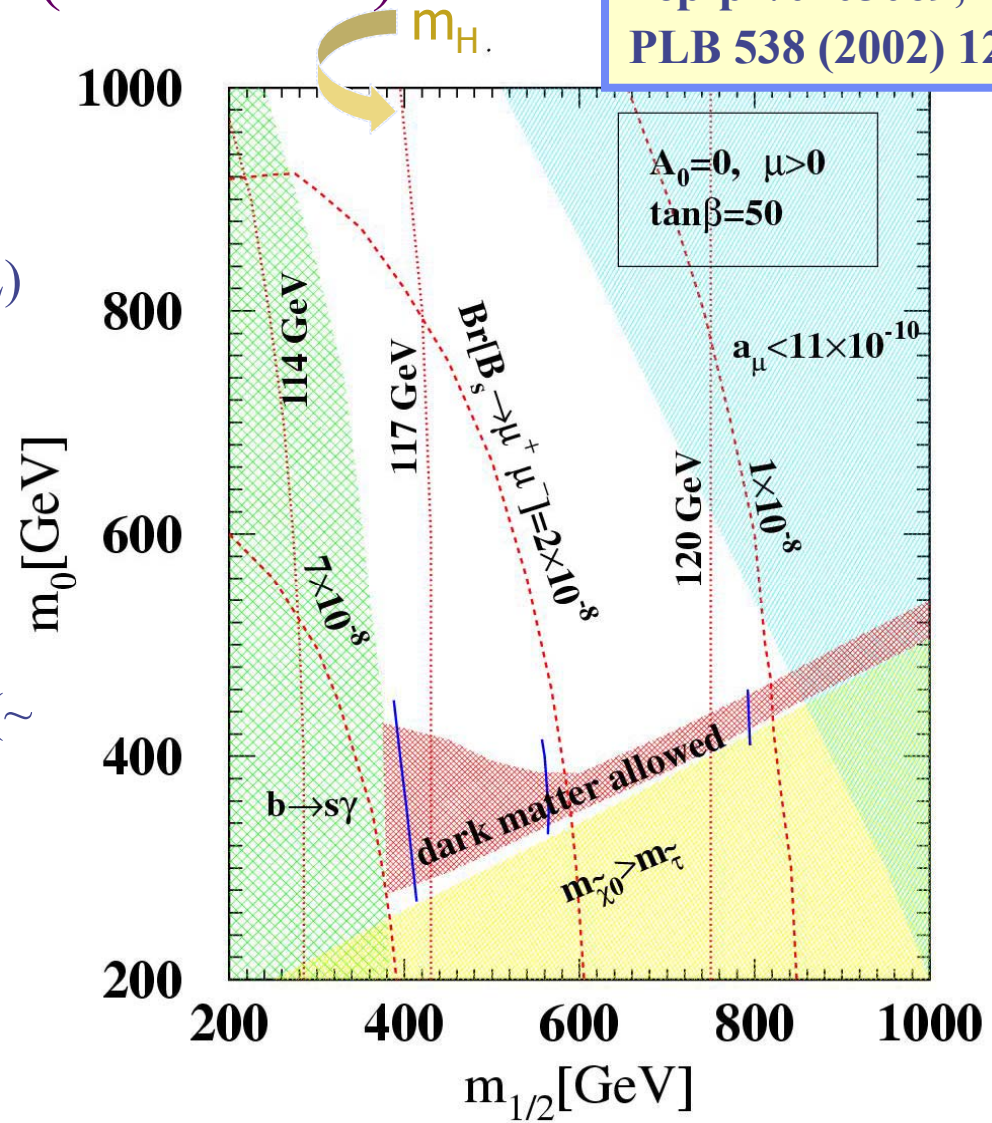
  our signal sample - not used for xchecks

- 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

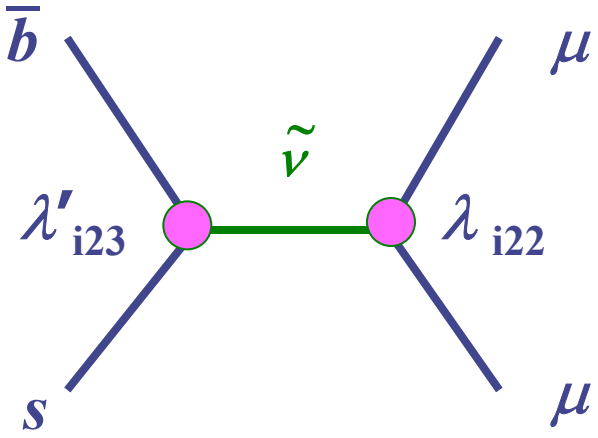
- Overlap with measured δa_μ (BNL) in mSUGRA parameter space.
- Overlap with dark matter=LSP allowed region.
- Eliminate large parameter space (~ all for tanβ>40), with $Br(B_s \rightarrow \mu^+\mu^-) \sim 10^{-8}$ in Run2 (15/fb)

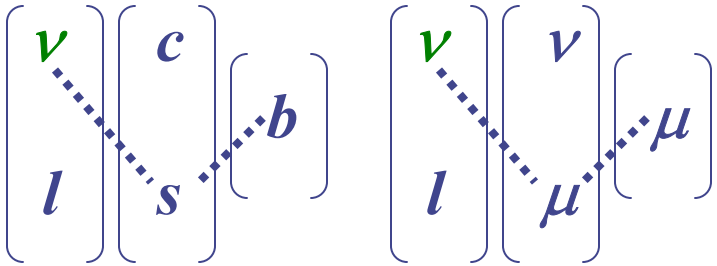


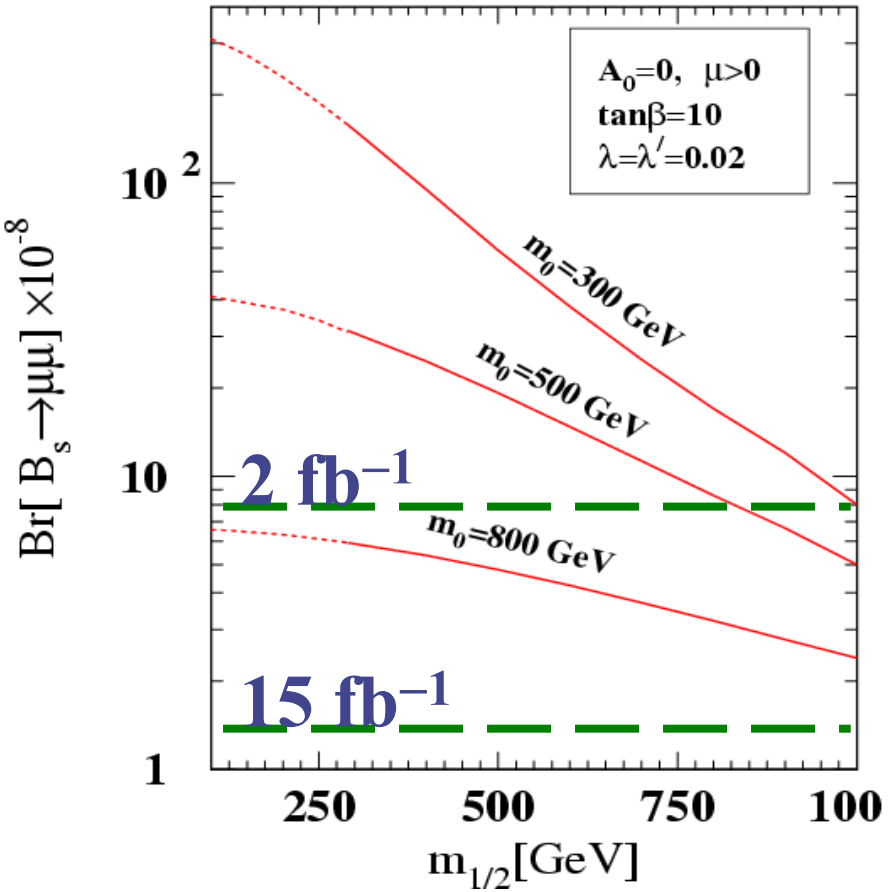
R_P Violation: *Br* vs. $m_{1/2}$

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

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

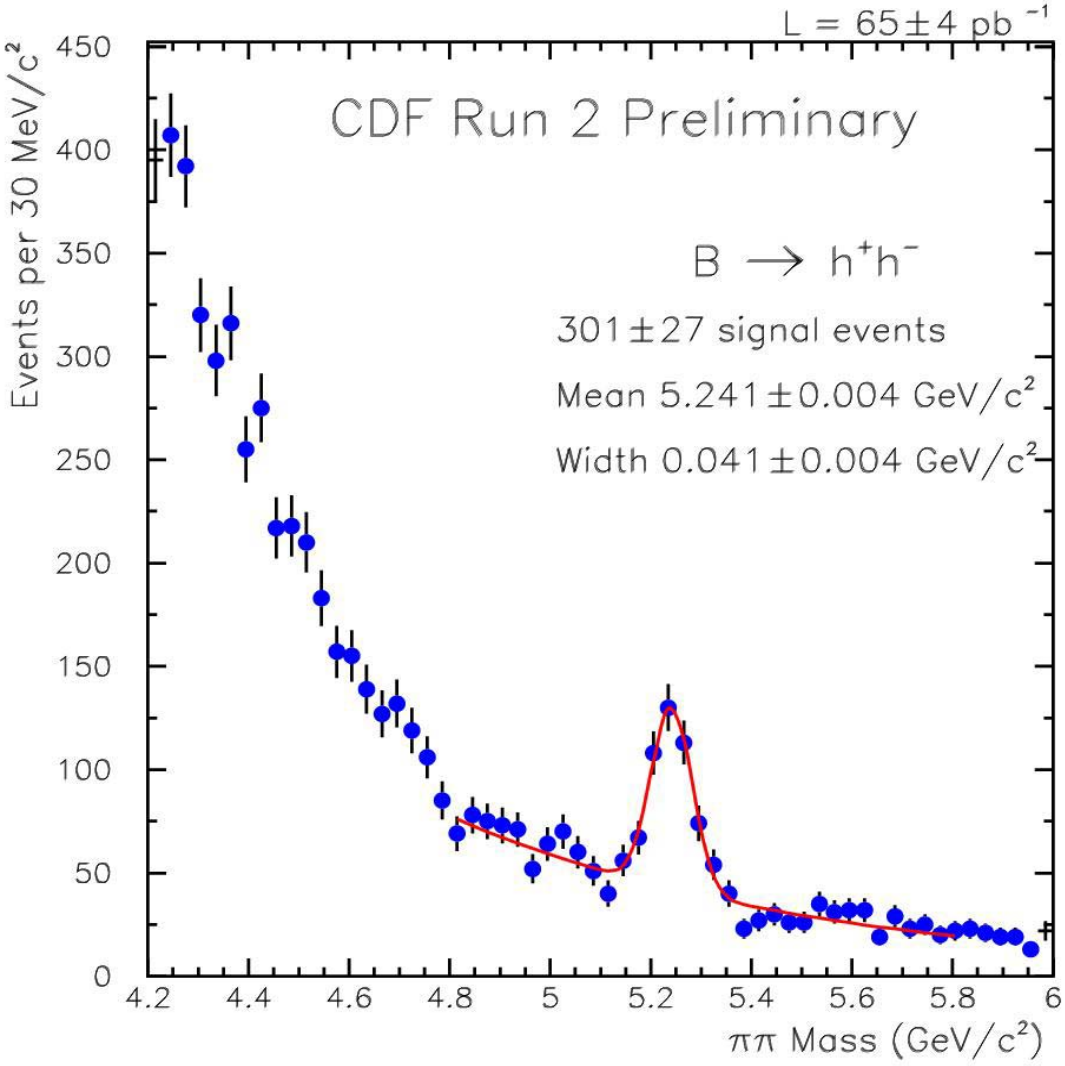






B→hh PR plot

now ~1K events with 180/pb



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

CDF, PRD 57, 3811 (1998)

$\int Ldt = 98\ \text{pb}^{-1}$ (~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)

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

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