Rare B Decays at the Tevatron

CIPANP 2006
San Juan Puerto Rico

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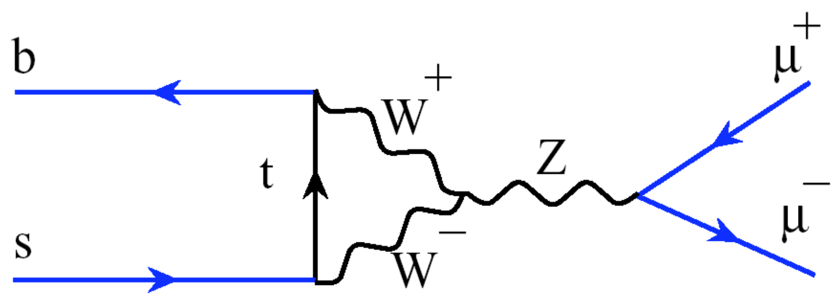
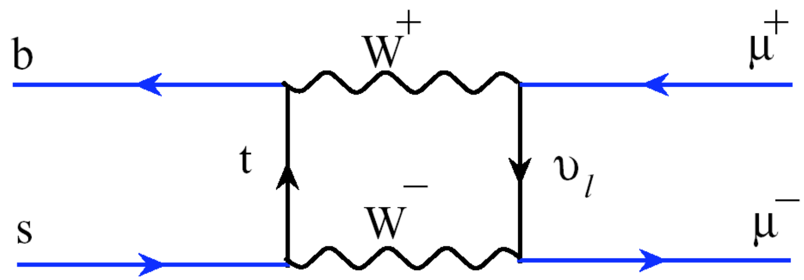
Representing the DØ an CDF collaborations

Flavor changing neutral currents

- FCNC's are forbidden at tree level, $B \rightarrow l^+l^-$ decays are also helicity suppressed
- SM: $BR(B_s \rightarrow \mu^+\mu^-) \sim 3.4\times10^{-9}$
  - depends only on one SM operator in effective Hamiltonian, hadronic uncertainties are small
- B_d relative to B_s suppressed by $|V_{td}/V_{ts}|^2 \sim 0.04$ if no additional sources of flavor violation
- Taus are difficult to detect, muon modes provide easy trigger





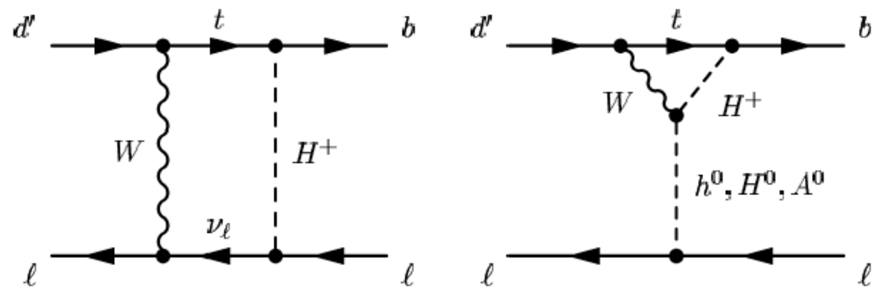
SM expectations:

	$Br(B_d \rightarrow l^+l^-)$	$Br(B_s \rightarrow l^+l^-)$
e	3.4×10^{-15}	8.0×10^{-14}
μ	1.0×10^{-10}	**3.4×10^{-9}**
τ	3.1×10^{-8}	7.4×10^{-7}

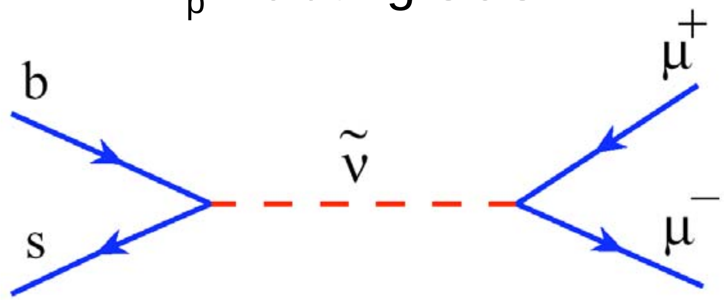
New physics in FCNC's

- excellent probe for new physics
  - tiny SM branching ratio with small theoretical uncertainty
- particularly sensitive to models with extended Higgs sector
  - BR grows ~ $\tan^6\beta$ (up to 3 orders of magnitude) in MSSM
  - 2HDM models ~ $\tan^4\beta$
  - mSUGRA: BR correlated with shift of $(g-2)_\mu$ - BNL measurement implies a factor of 10-100 enhancement.
- Many other scenarios can contribute
  - minimal SO(10) GUT models
  - R_p violating models, contributions at tree level
  - (neutralino) dark matter
  - …

Two-Higgs Doublet models:

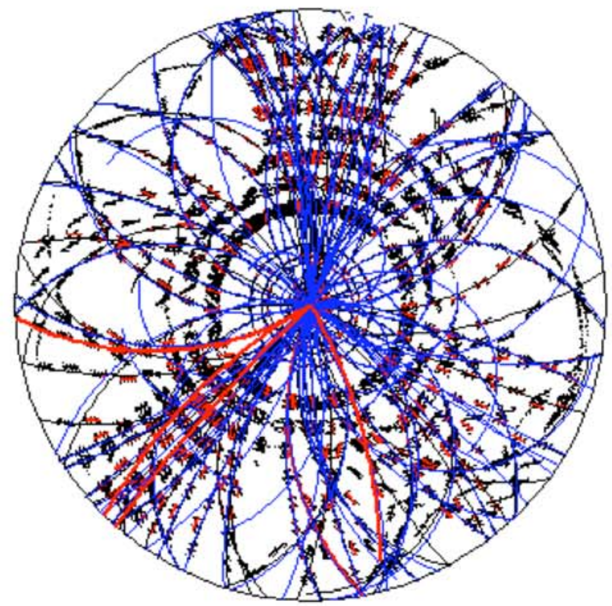


R_p violating SUSY:

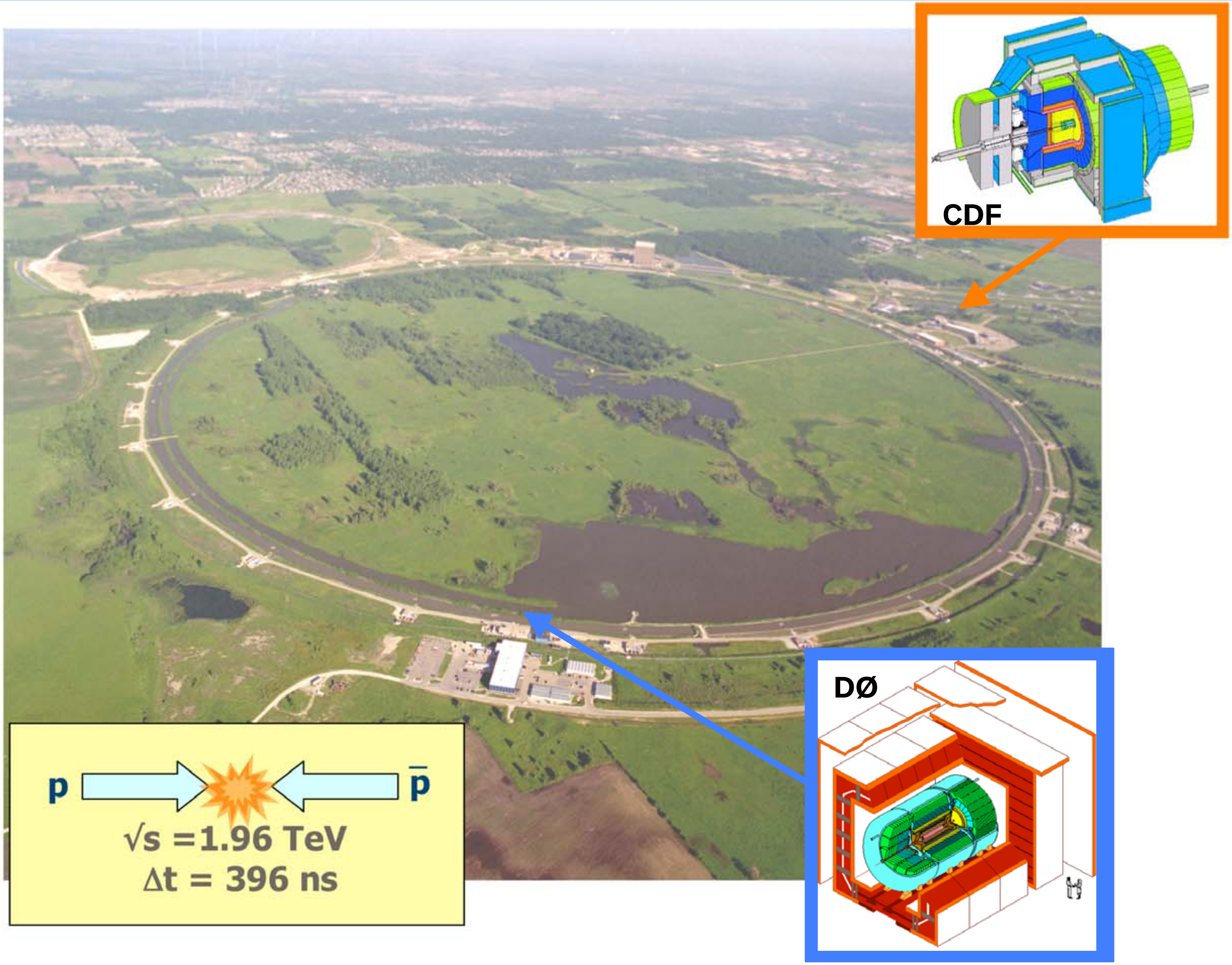


B Physics at Hadron Colliders

- Pros
  - Large production cross section – 300 Hz of reconstructable B's
  - All b species produced
    - $B^{\pm}$, B^0, B_s, B_c, Λ_b, Ξ_b
  - We get to look for the Higgs at the same time
- Cons
  - Large combinatorics and messy events
  - We only write about 50 Hz of data total, which we have to share with other physics
  - Inelastic cross section is a factor of 10^3 larger with roughly the same pT spectrum – difficult to trigger on B's
  - Many decays of interest have BR's of the order 10^{-6} – hard to separate from "regular" B decays at the trigger level
  - Difficult to detect low pT photons and pi0's from B decays

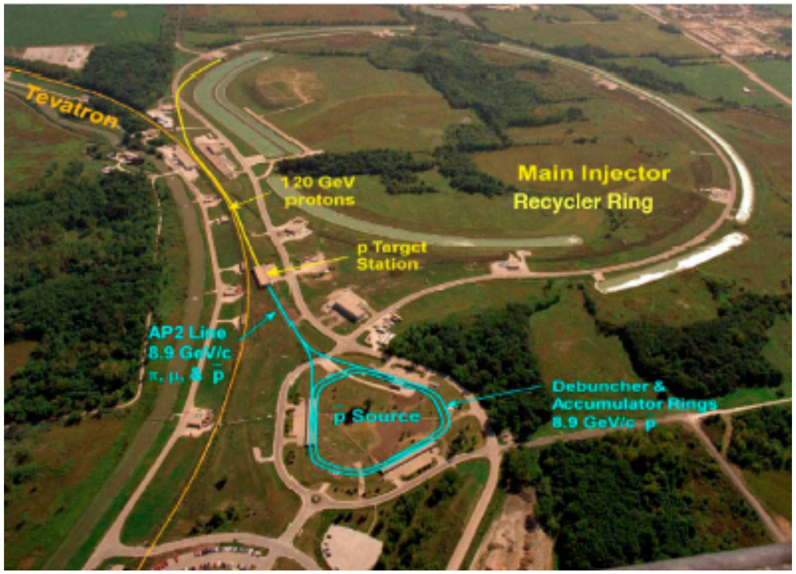


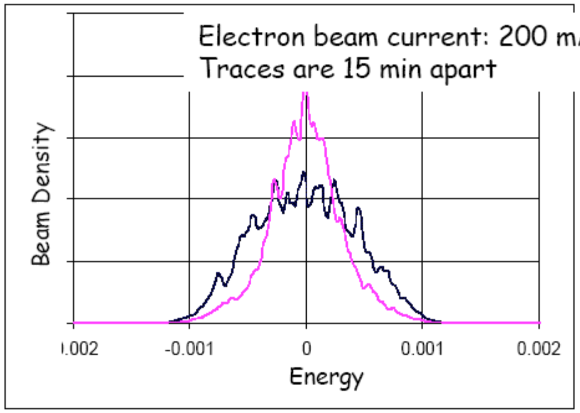
The Fermilab Tevatron

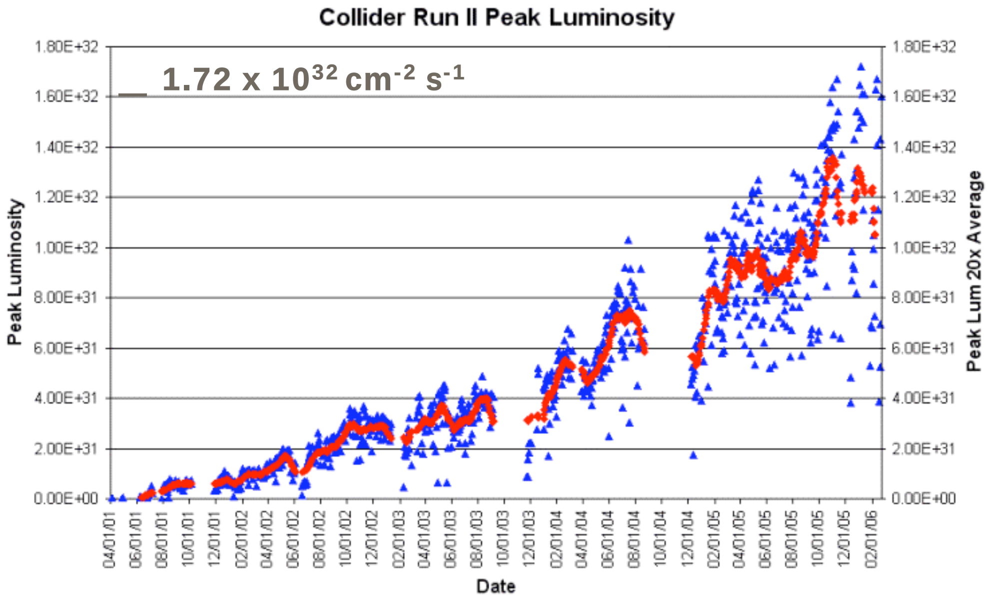


Another Record Year for the Tevatron

- More protons on target
- Better collection efficiency
- Electron cooling in the pbar recycler



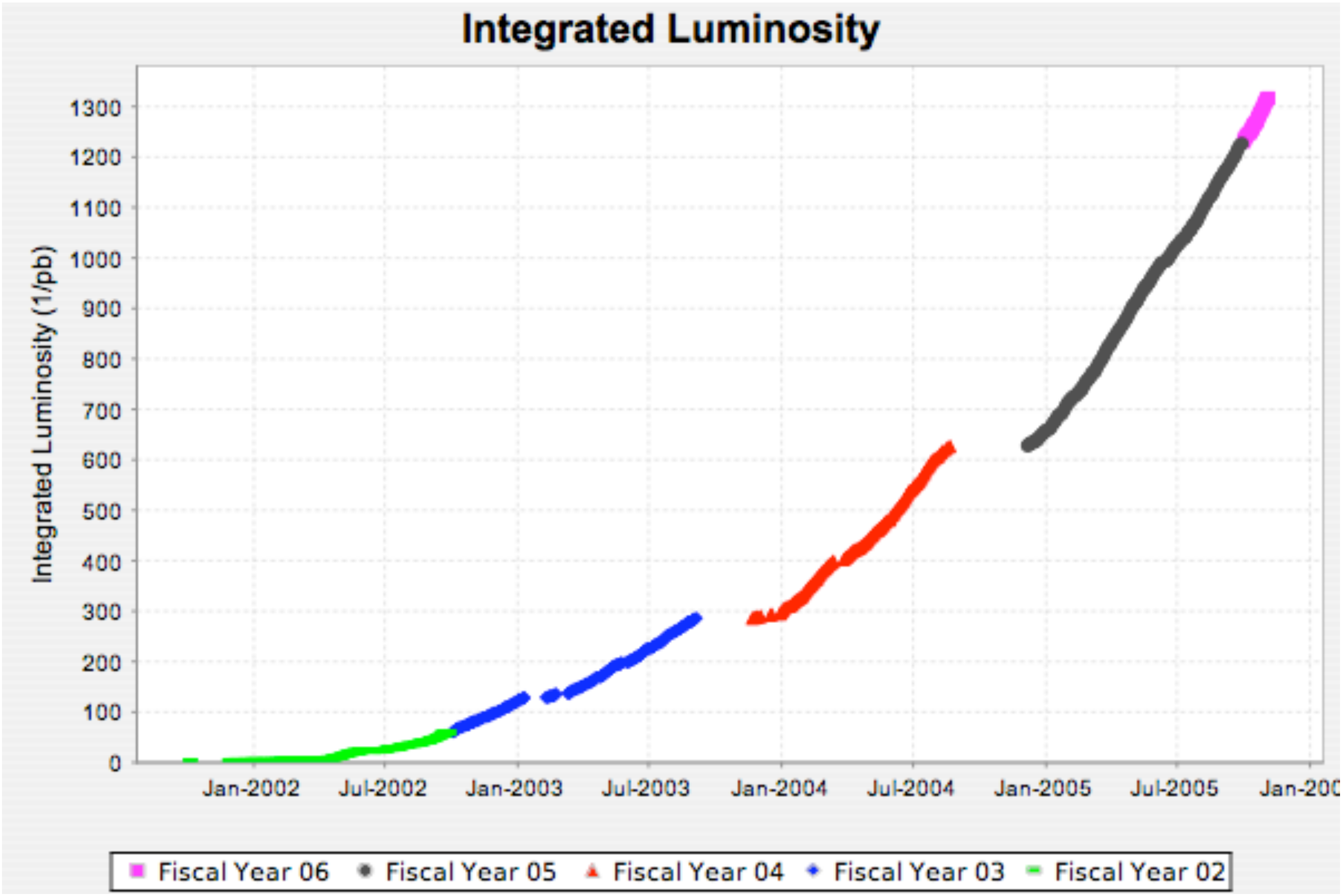




- Antiproton stacking records:
  - Stacking rate, 20 mA/hr
- Integrated luminosity records:
  - > 20 pb^{-1} / week
  - > 5 pb^{-1} / day

Tevatron luminosity

- Over 1 fb^{-1} of collisions have been delivered to the experiments so far in Run II

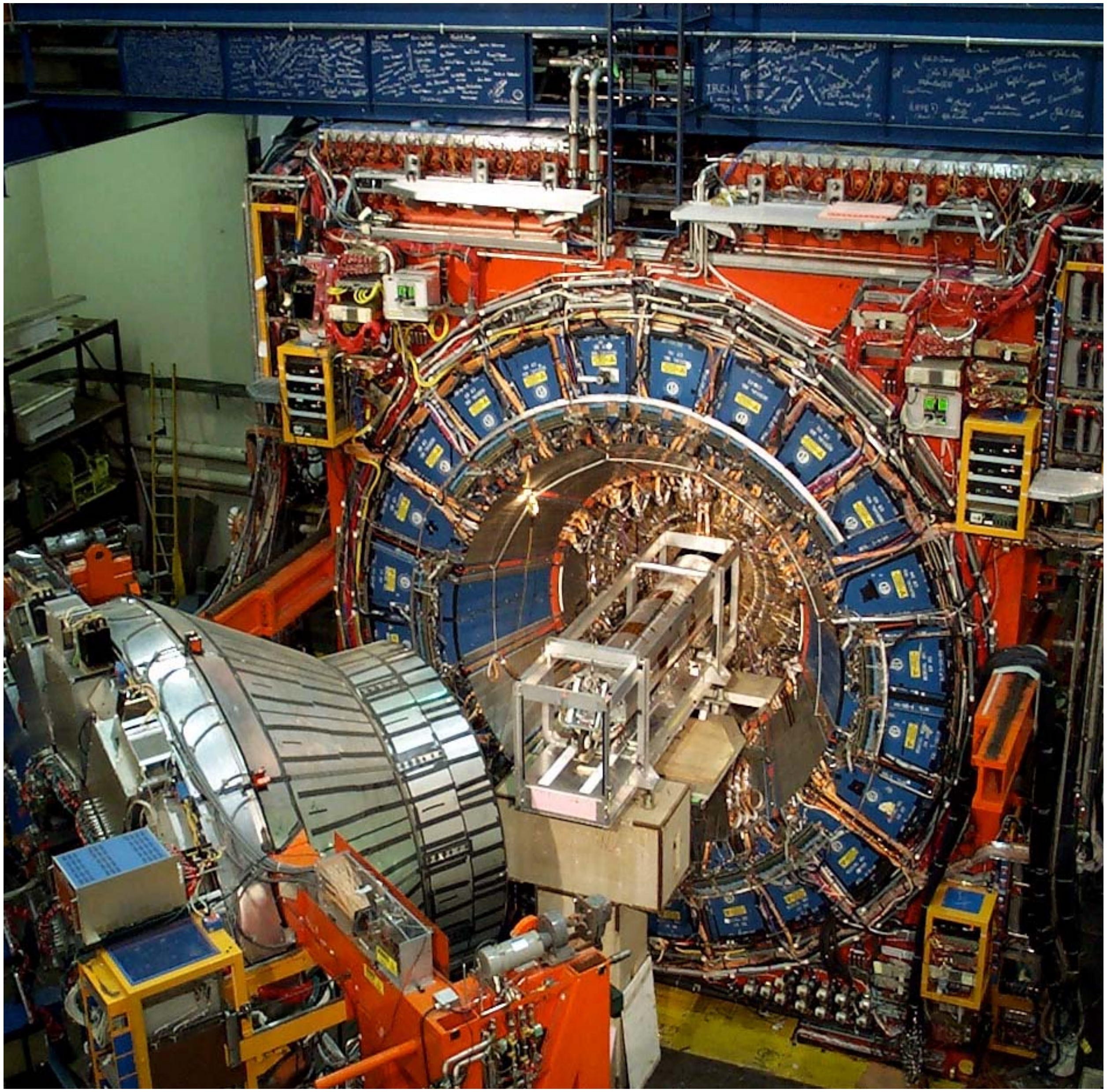


The DØ Run II Detector

- Silicon vertex detector
  - $|\eta| < 3.0$
- Central fiber tracker and pre-shower detectors
  - $|\eta| < 1.5$
- 2 T solenoid magnet
- New low pT central muon trigger scintillators
- New forward μ system
  - Excellent muon purity and coverage: $|\eta| < 2.0$
- Second level silicon track trigger being commissioned, B tagging at 3rd level now

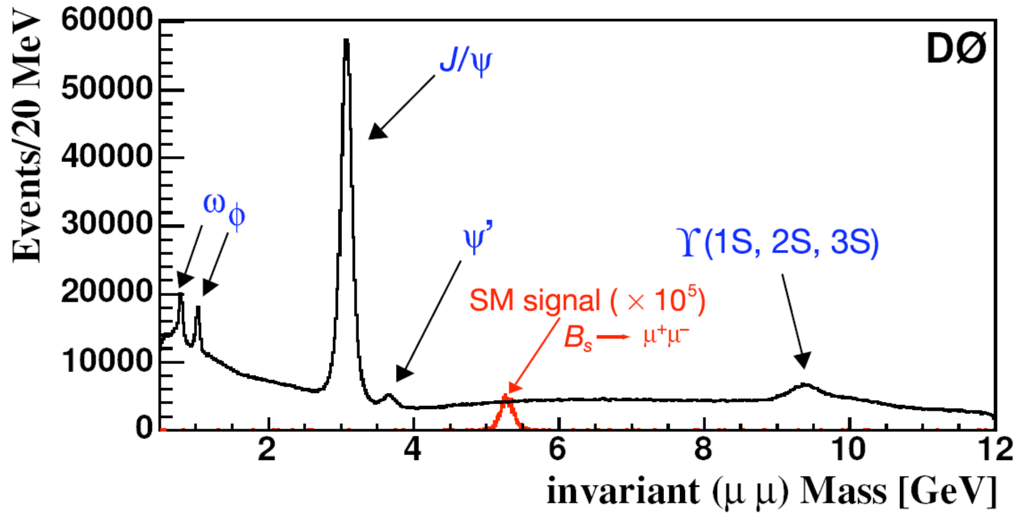
The CDF Run II Detector

- New silicon vertex detector
  - inner layer at 1.35 cm
- New central tracker
  - Excellent mass resolution
- Extended μ coverage
- TOF and dE/dx particle ID
- Second level impact parameter trigger
  - Allows all hadronic B decay triggers



$B \to \mu^+\mu^-$ experimental search

- **CDF:**
  - 780 pb^{-1} di-muon triggered data
  - two separate search channels
    - central/central muons
    - central/forward muons
  - extract B_s and B_d limit
- **DØ:**
  - 300 pb^{-1} di-muon triggered data
  - Sensitivity for 1fb^{-1} of recorded data
- **both experiments:**
  - blind analysis
  - side bands for background determination
  - use $B^+ \to J/\psi\ K^+$ as normalization mode

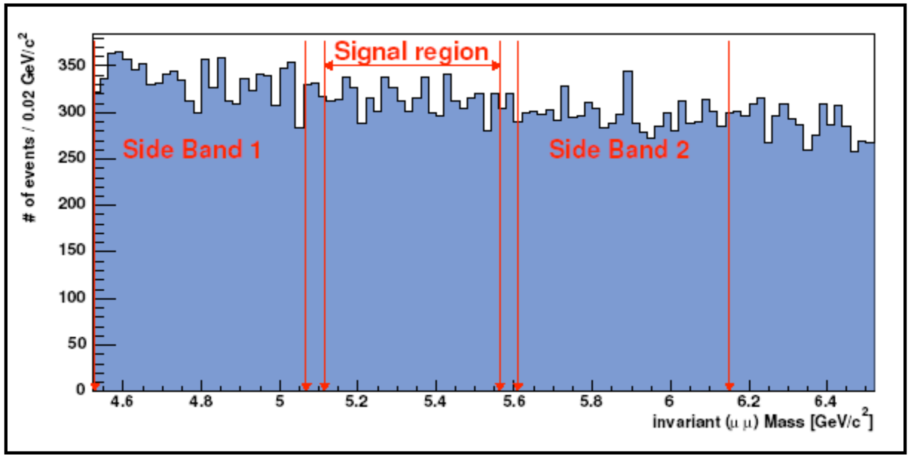


signal region:
DØ: $5.160 < m_{\mu\mu} < 5.520$ GeV/c^2;
$\pm 2\sigma$ wide, σ=90 MeV
CDF: $5.169 < m_{\mu\mu} < 5.469$ GeV/c^2;
covering B_d and B_s; σ=25 MeV

Pre-selection

- **Pre-selection DØ:**
  - $4.5 < m_{\mu\mu} < 7.0$ GeV/c^2
  - muon quality cuts
  - $p_T(\mu)>2.5$ GeV/c
  - $|\eta(\mu)| < 2$
  - $p_T(B_s$ cand.$)>5.0$ GeV/c
  - good vertex
- **Pre-Selection CDF:**
  - $4.669 < m_{\mu\mu} < 5.969$ GeV/c^2
  - muon quality cuts
  - $p_T(\mu)>2.0$ (2.2) GeV/c CMU (CMX)
  - $p_T(B_s$ cand.$)>4.0$ GeV/c
  - $|\eta(B_s)| < 1$
  - good vertex
  - 3D displacement L_{3D} between primary

  and secondary vertex
  - $\sigma(L_{3D})<150$ μm
  - proper decay length $0 < \lambda < 0.3$ cm

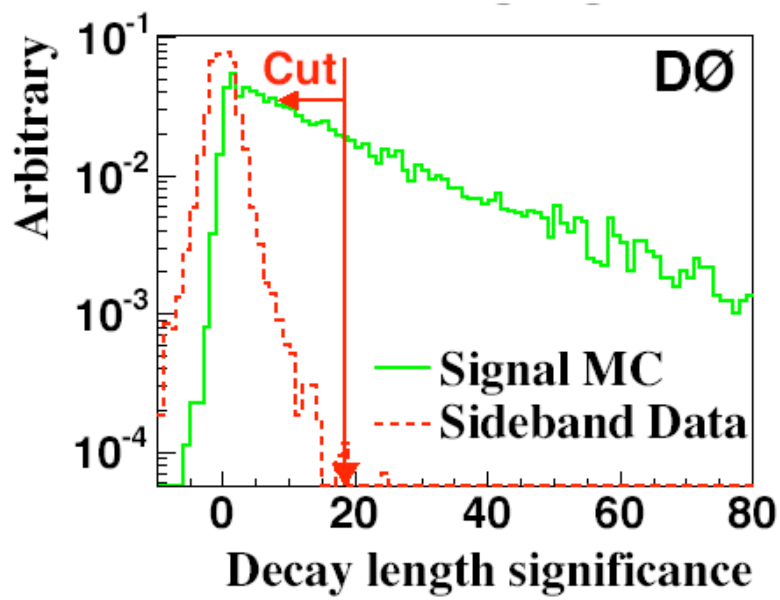


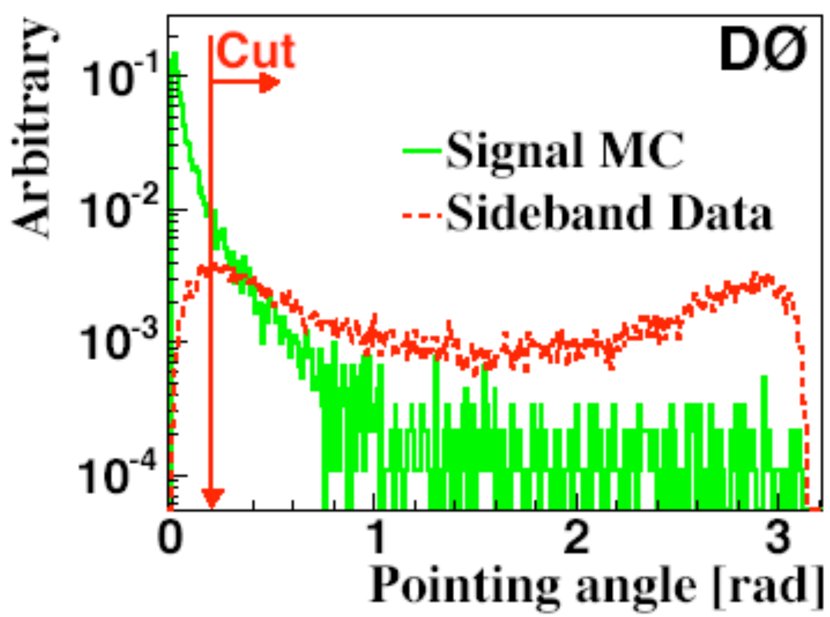
e.g. DØ: about 38k events after pre-selection

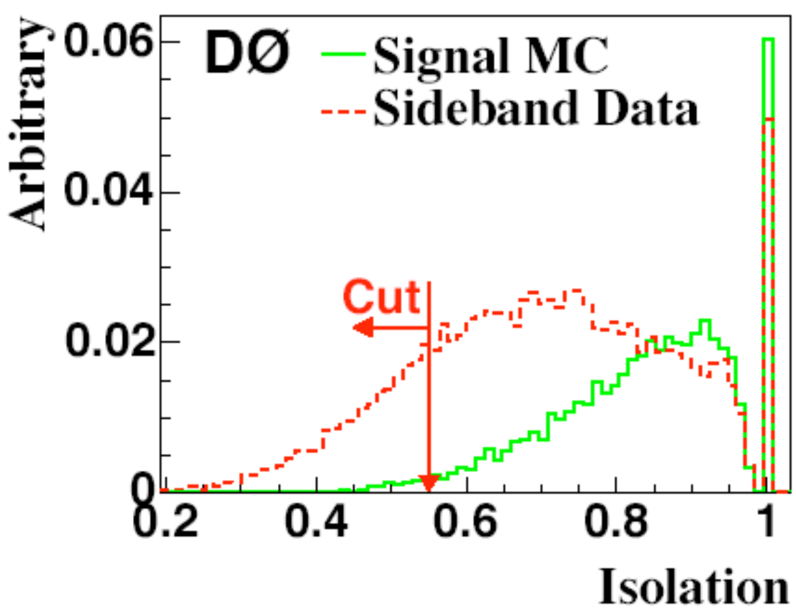
Potential sources of background:
- continuum μμ Drell-Yan
- sequential semi-leptonic b->c->s decays
- double semi-leptonic bb-> μμX
- b/c->μx+fake
- fake + fake

DØ cut optimization

- optimize cuts on three discriminating variables
  - angle between $\mu^+\mu^-$ and decay length vector (pointing consistency)
  - transverse decay length significance (B_s has lifetime): $L_{xy}/\sigma(L_{xy})$
  - isolation in cone around B_s candidate

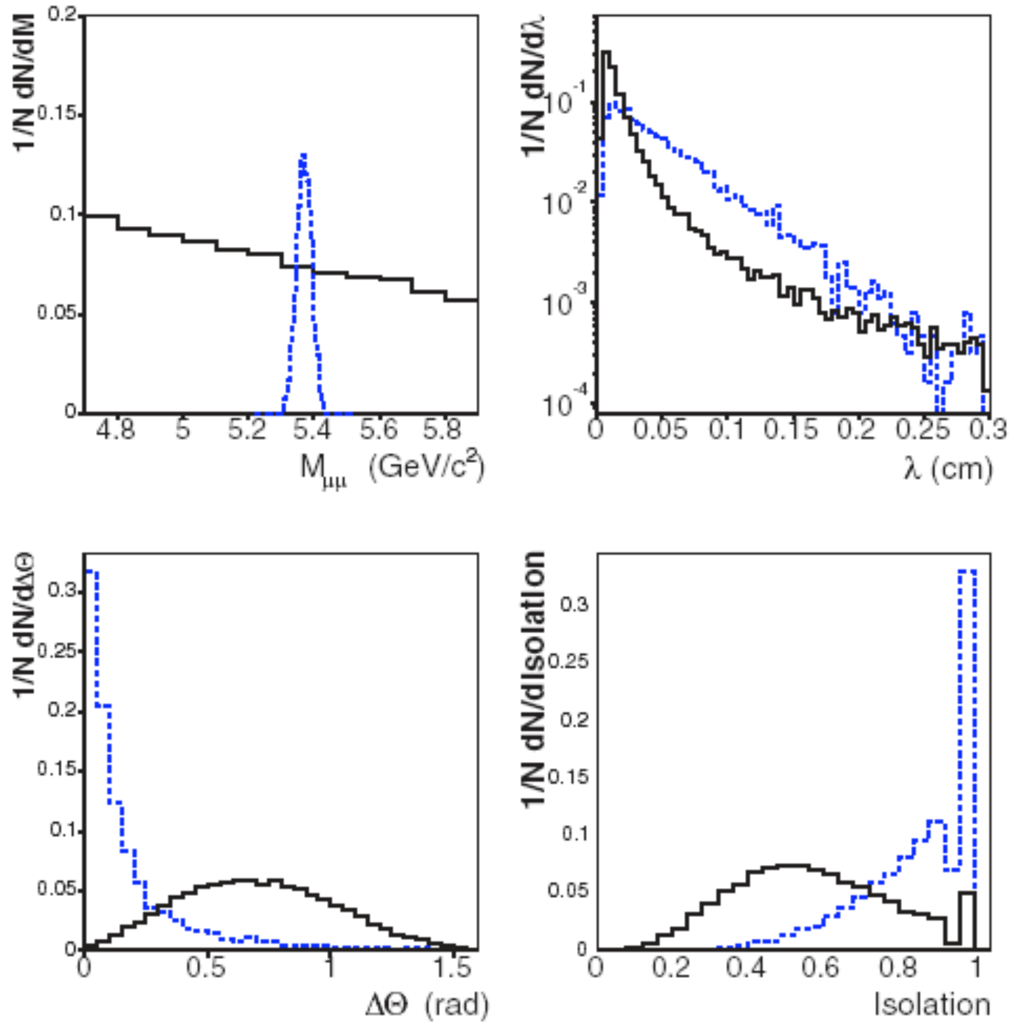


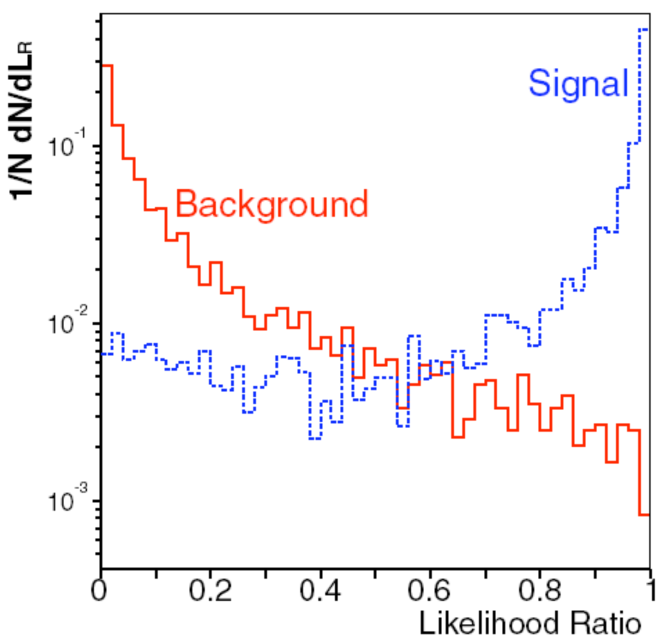




CDF cut optimization

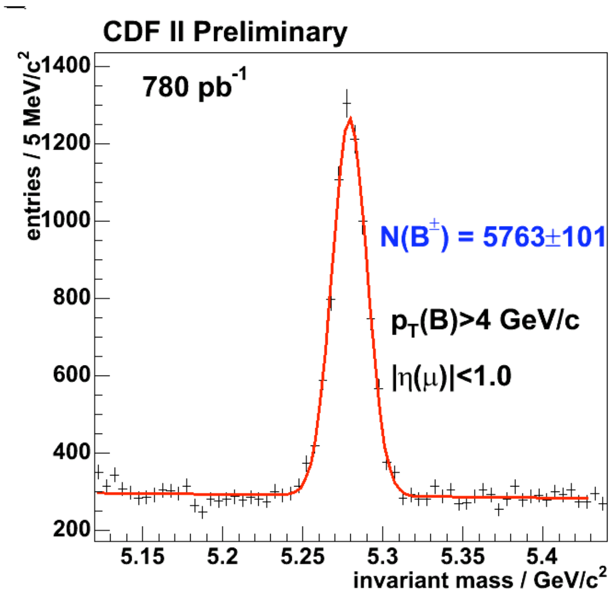
- discriminating variables
  - pointing angle between $\mu^+\mu^-$ and decay length vector
  - isolation in cone around B_s candidate
  - proper decay length probability $p(\lambda) = \exp(-\lambda/\lambda_{Bs})$

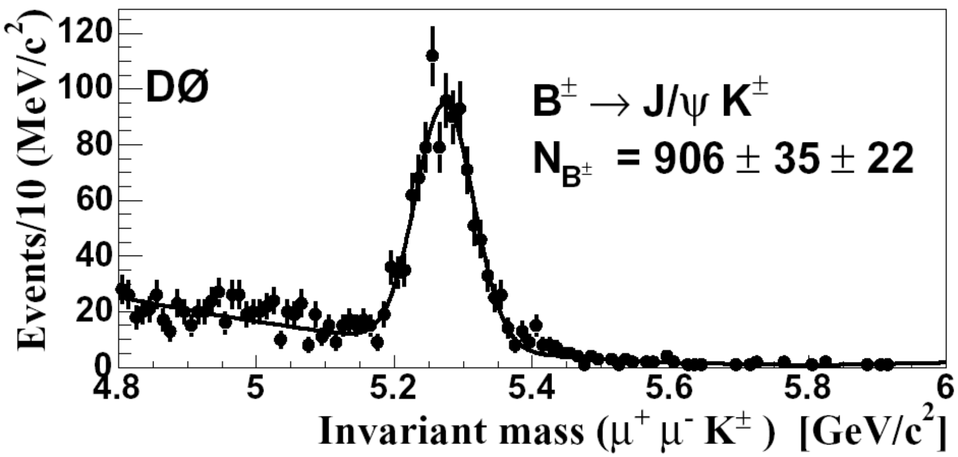




Normalization

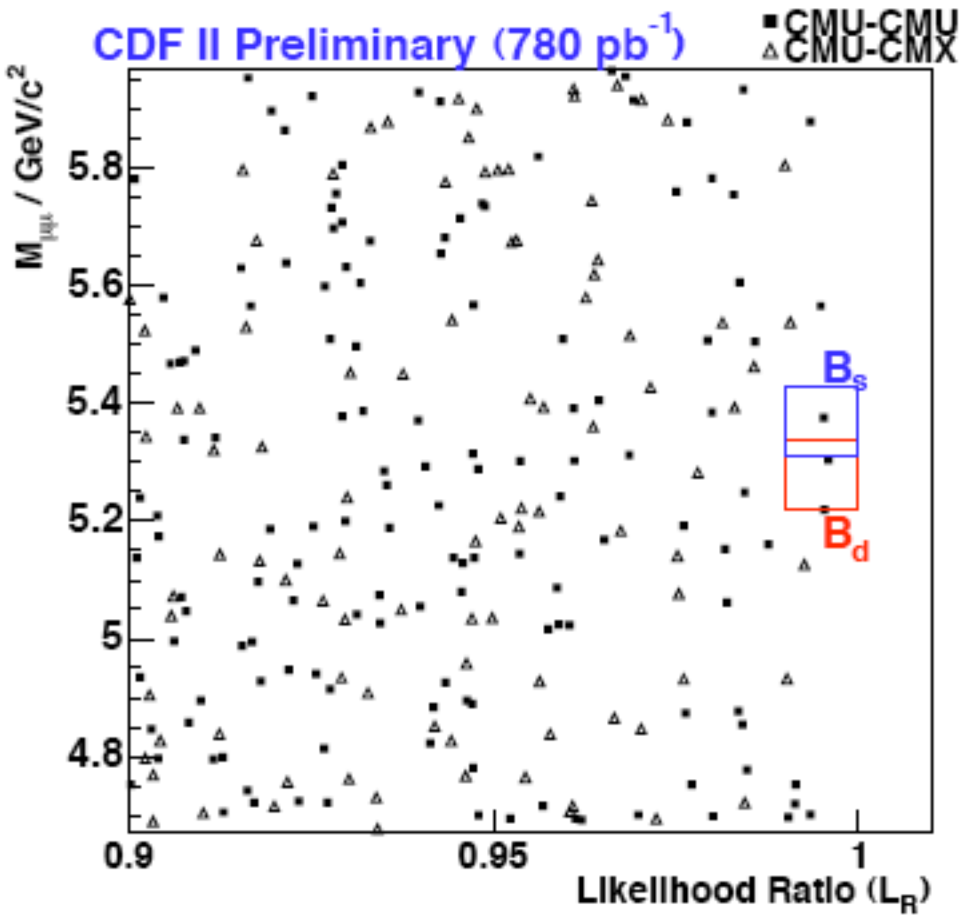
- relative normalization is done to $B^+ \to J/\psi\ K^+$
- advantages:
  - $\mu^+\mu^-$ selection efficiency same
  - high statistics
  - BR well known
- disadvantages:
  - fragmentation $b \to B_u$ vs. $b \to B_s$
- DØ: apply same values of discriminating cuts on this mode
- CDF: no likelihood cut on this mode





Opening the CDF box

- central/central: observe 1 (0) events, consistent with background expectations
- Central/forward: observe 2 (0), also consistent with background

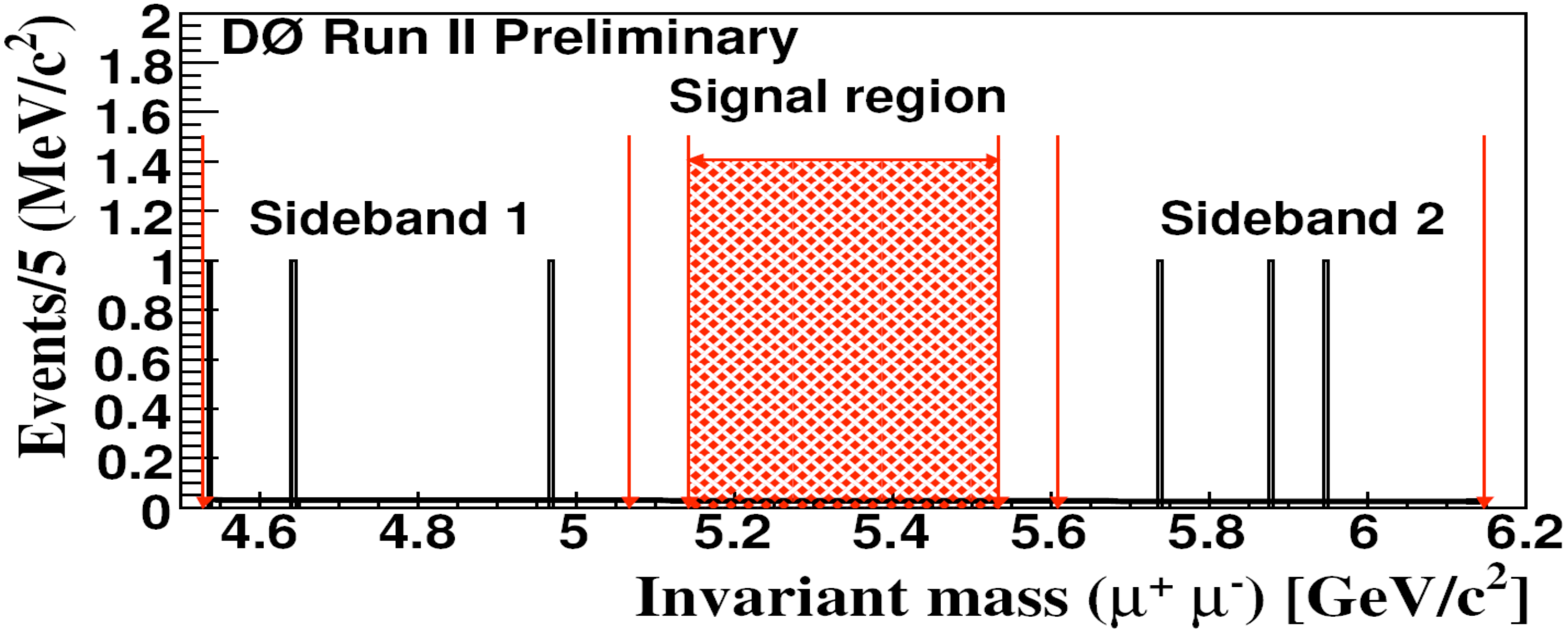


$BR(B_s \to \mu^+\mu^-) < 1\times10^{-7}$ @ 95% C.L

$BR(B_d \to \mu^+\mu^-) < 3\times10^{-8}$ @ 95% C.L

DØ Sensitivity 700 pb^{-1}

- Waiting for full Run2a data set to open box



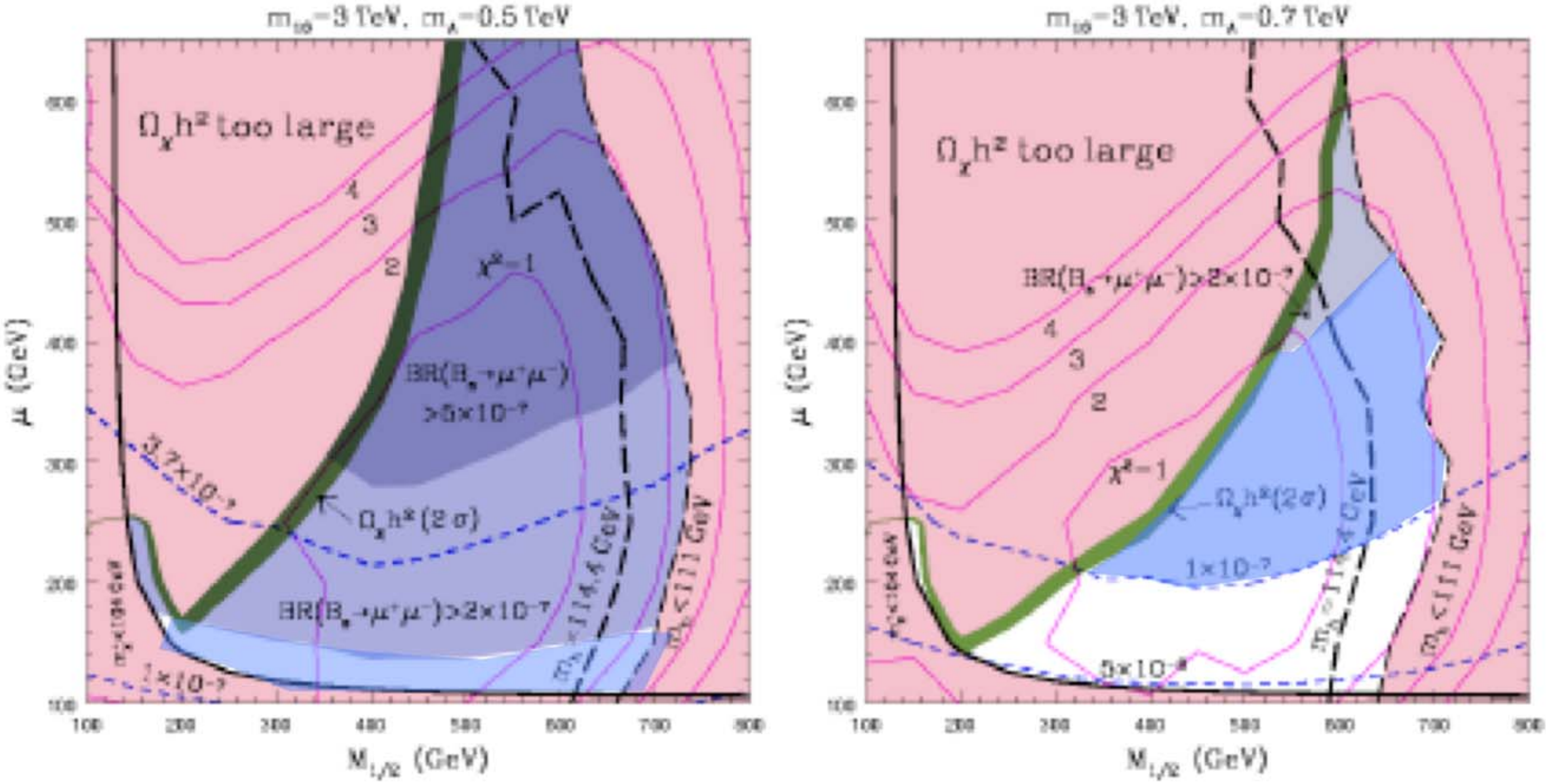
Expect 2.2 ± 0.7 background events

$B \to \mu^+\mu^-$ limits

- CDF sets separate limits on B_s and B_d channels - B_d BR can be bigger in non-minimum flavor violating models.
- DØ mass resolution is not sufficient to separate B_s from B_d. Assume no B_d contribution (conservative)

Exp/mode	Lumi	BR limit	Status
CDF $B_d \to \mu\mu$	364 pb^{-1}	4.9×10^{-8}	Published
CDF $B_d \to \mu\mu$	780 pb^{-1}	3.0×10^{-8}	Prelim.
DØ $B_s \to \mu\mu$	240 pb^{-1}	5.1×10^{-7}	Published
CDF $B_s \to \mu\mu$	364 pb^{-1}	2.0×10^{-7}	Published
DØ $B_s \to \mu\mu$	300 pb^{-1}	3.5×10^{-7}	Prelim.
Combined $B_s \to \mu\mu$	300/364 pb^{-1}	1.5×10^{-7}	Prelim.
DØ $B_s \to \mu\mu$	700 pb^{-1}	2.3×10^{-7}	Prelim. Sensitivity
CDF $B_s \to \mu\mu$	780 pb^{-1}	1.0×10^{-7}	Prelim.

Constraints from $B_s \to \mu^+\mu^-$



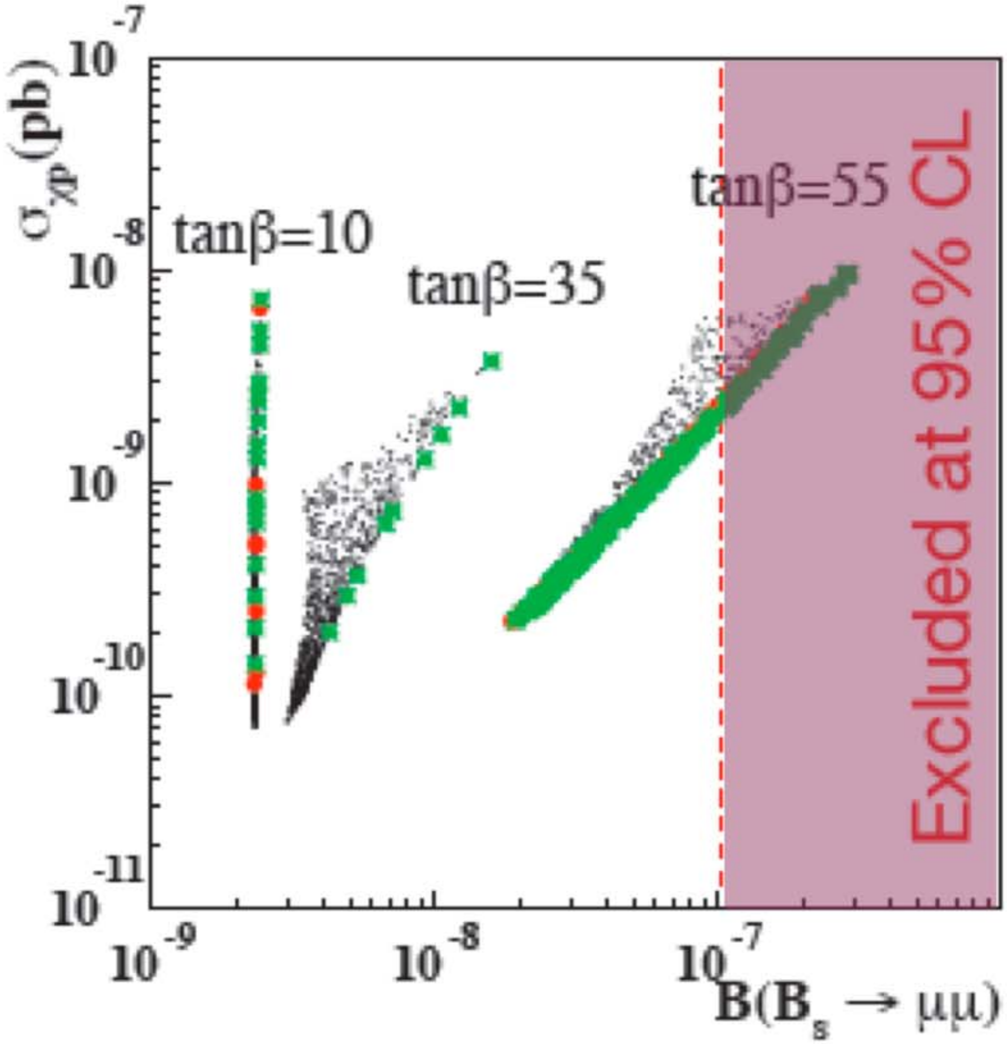
Minimal SO_{10} SUSY

R. Dermíšek, *et al.*, hep-ph/0507233

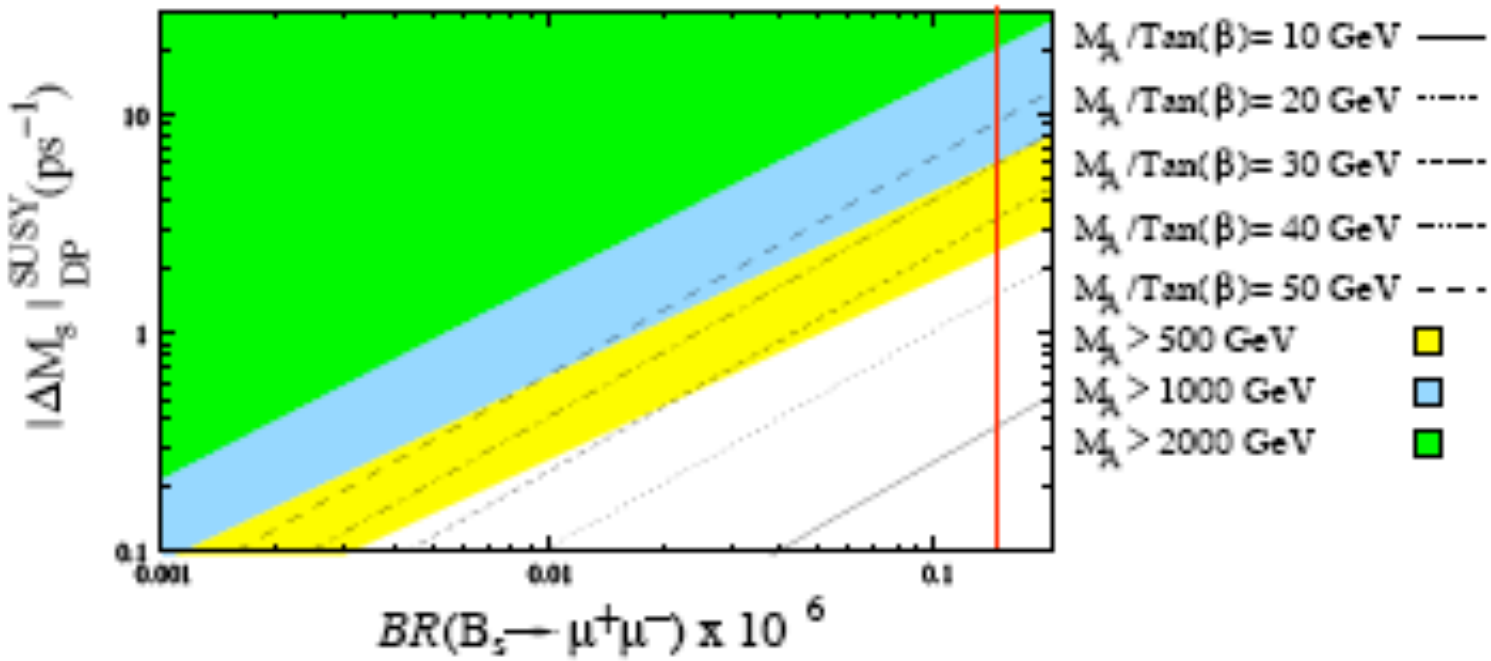
Constraining dark matter

- mSUGRA model:
  - strong correlation between BR($B_s \to \mu^+\mu^-$) and neutralino dark matter cross section, especially for large tanβ
  - constrain neutralino cross section to be consistant with relic density from WMAP

S. Baek et al.,
JHEP 0502 (2005) 067



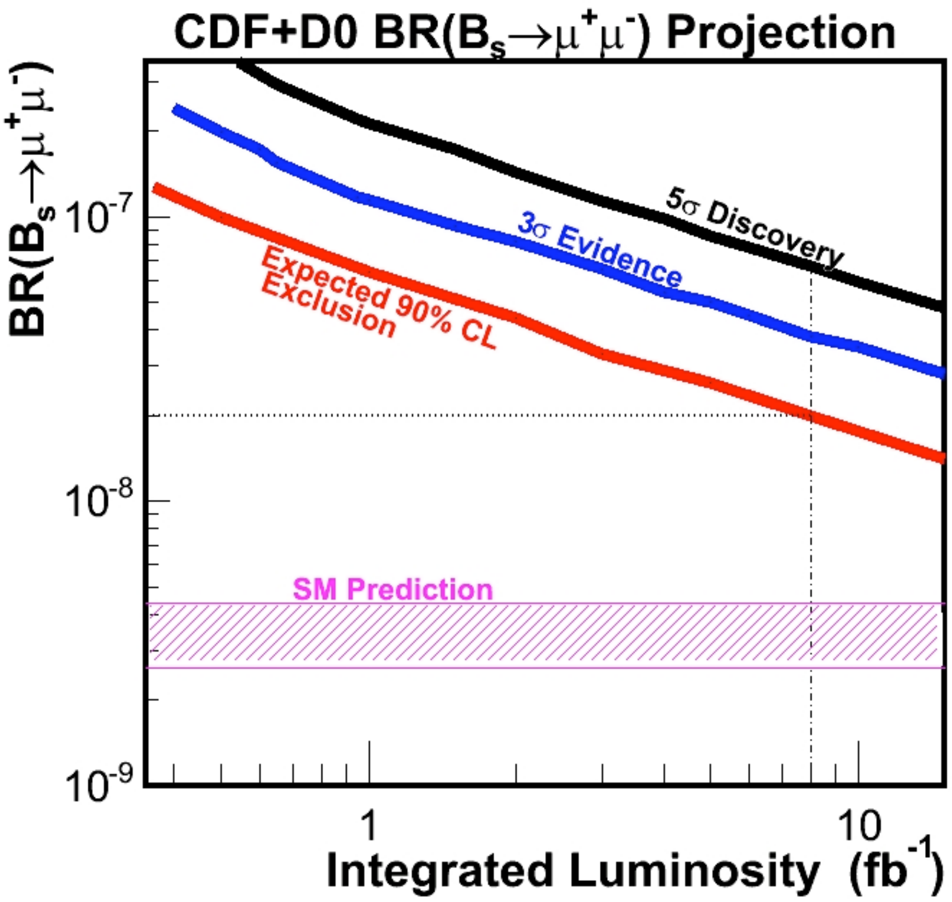
Still room for new physics



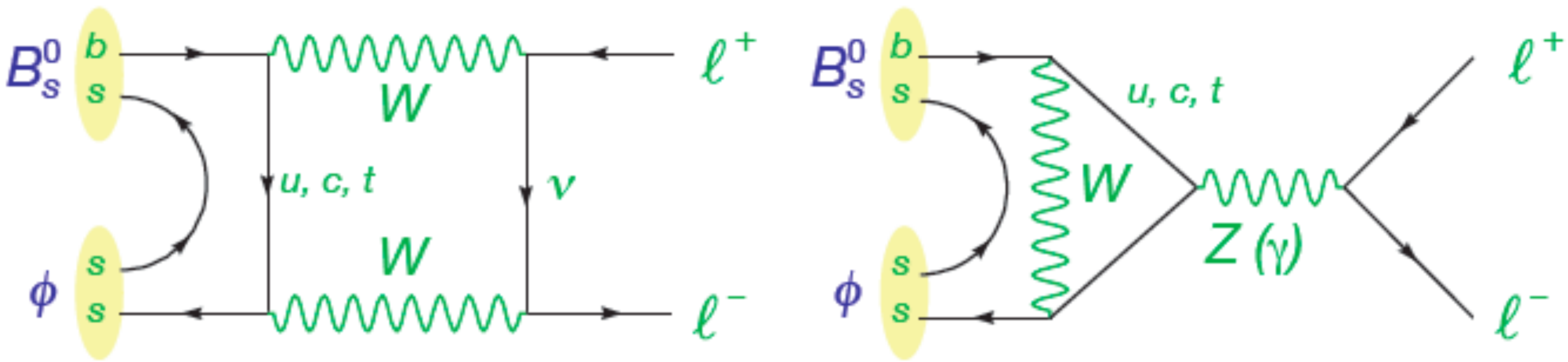
M. Carena et al, hep-ph/0603106

Future Prospects for $B_s \to \mu^+\mu^-$

- assuming unchanged analysis techniques, reconstruction and trigger efficiencies are unaffected with increasing luminosity
  - we are actually working on getting better
- for $8 fb^{-1}$ per experiment an exclusion at 90%C.L. down to 2×10^{-8} is possible
  - but we are really looking for new physics here!



Search for $B_s \to \phi\mu^+\mu^-$

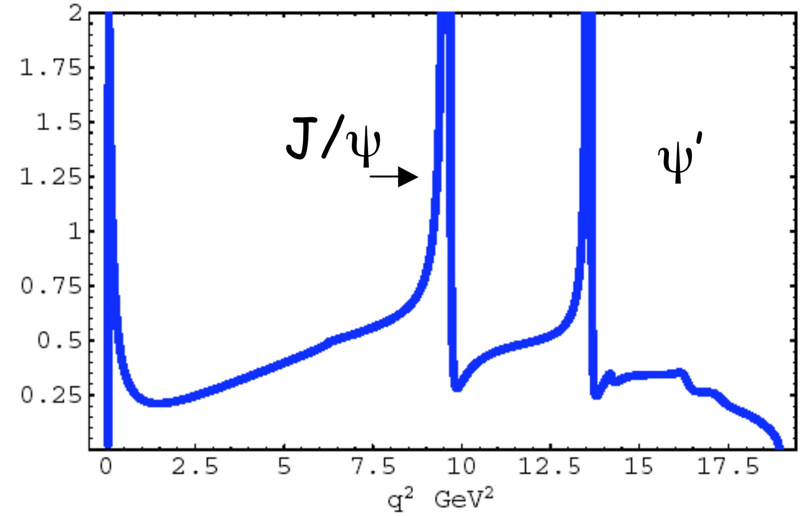


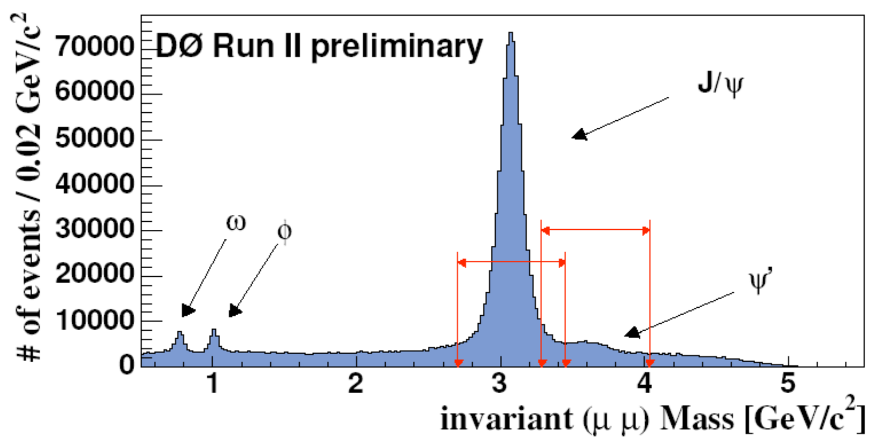
- investigate $b \to s\ l^+l^-$ FCNC transitions in B_s meson
  - theorists want inclusive rate, but that's very difficult experimentally
  - complimentary to B_d measurements at B factories
- exclusive decay: $B_s \to \phi\mu^+\mu^-$
  - SM prediction: BR: ~1.6×10^{-6}
  - about 30% uncertainty due to $B_s \to \phi$ form factor
- again, this is a good place to look for new physics
  - 2HDM: enhancement possible, depending on parameters for $\tan\beta$ and $M_{H+,}$ etc, etc.

Search for $B_s \to \phi\mu^+\mu^-$

- DØ: 300 pb^{-1} of dimuon data
- cut on mass region $0.5 < M(\mu\mu) < 4.4$ GeV/c^2 excluding J/ψ and ψ'
- two good muons, $p_t > 2.5$ GeV/c
- two additional oppositely charged tracks $p_T > 0.5$ GeV/c for ϕ
- ϕ candidate in mass range 1.008 $< M(\phi) < 1.032$ GeV/c^2
- good 4 track vertex
- $p_t(B_s$ cand.$) > 5$ GeV/c
- normalize to resonant decay $B_s \to J/\psi\ \phi$

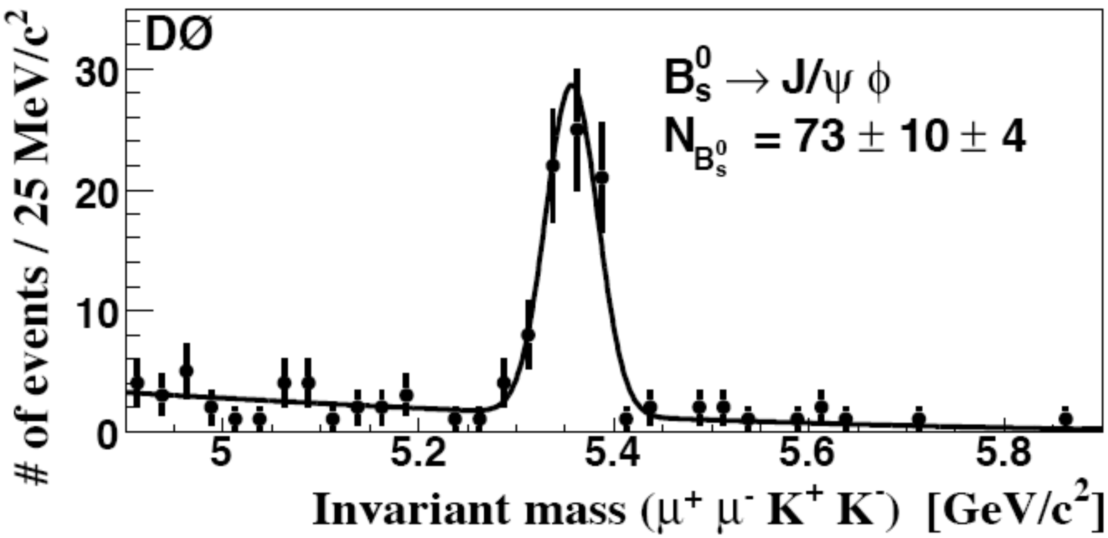
Dilepton mass spectrum
in b -> s l l decay





Search for $B_s \to \phi\mu^+\mu^-$

- Blind analysis: optimization with following variables in random grid search
  - Pointing angle
  - Decay length significance
  - Isolation
- Background modeled from sidebands
- Use resonant decay $B_s \to J/\psi\ \phi$ with same cuts as normalization
- Gaussian fit with quadratic background: 73 ± 10 ± 4 $B_s \to J/\psi\ \phi$ resonant decays



Limit on $B_s \to \phi \mu^+ \mu^-$

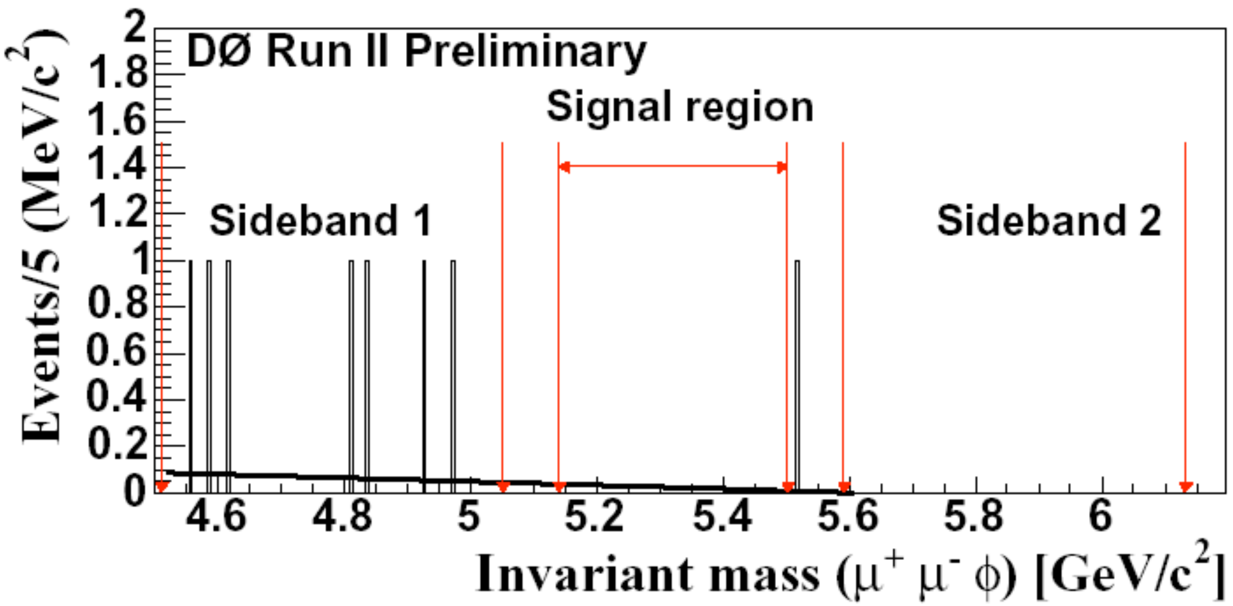
- expected background from sidebands: 1.6 ± 0.4 events
- observe zero events in signal region

$BR(B_s \to \phi\, \mu^+\mu^-)/BR(B_s \to J/\psi\, \phi) < 4.4 \times 10^{-3}$ @ 95% C.L.

Using central value for **$BR(B_s \to J/\psi\, \phi) = 9.3\times10^{-4}$ PDG2004:**

$BR(B_s \to \phi\, \mu^+\mu^-) < 4.1\times10^{-6}$ @ 95% C.L.

x10
improvement
w.r.t previous limit



Conclusions

- CDF and DØ have measured the world best limits on rare FCNC B decays
  - $B_s \to \mu^+\mu^-$ limits already provide important constraints on new physics
  - exclusive $B_s \to \mu^+\mu^-\phi$ sensitivity is only about 2x above SM

- Much more data to come, Tevatron is on track to double statistics every year
  - excellent discovery potential for new physics