Searches for non-SM physics in rare decays at the Tevatron

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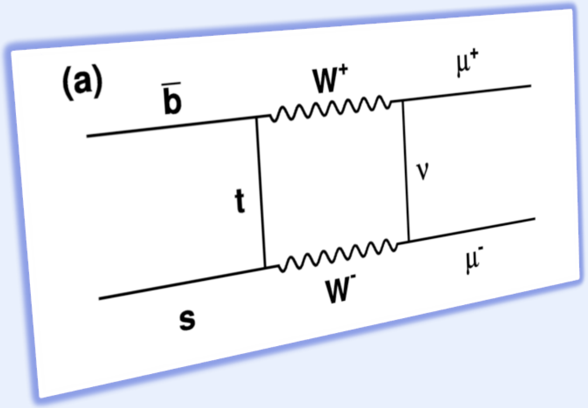
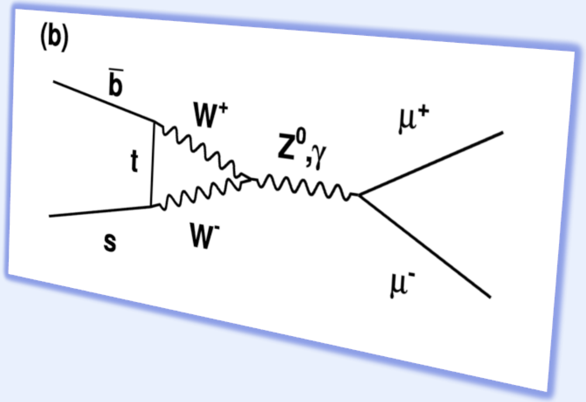
$B_{(s)} \to \mu\mu$





- CDF: 3.7 fb^{-1} CDF Public Note 9892
- DØ: 6.1 fb^{-1} PLB 693, 539 (2010)
- CDF update in progress: 7 fb^{-1}

$B_{(s)}$->μμ: Motivation

- Search for B_s-> μμ is an SM benchmark in flavour physics
- Can only occur through higher order FCNC diagrams (in SM)
- Good BSM probe:
  - small predicted SM cross section

$$\mathcal{BR}(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$

(Buras et al, JHEP 1009 (2010) 106)

  - very low theoretical uncertainties
  - large class of BSM models predict large enhancements of $\mathcal{BR}(B_s \to \mu\mu)$
  - clean signature
  - ratio of $\mathcal{BR}(B_s \to \mu^+\mu^-)/\mathcal{BR}(B_d \to \mu^+\mu^-)$ can be used to discriminate between various BSM models

$B_{(s)}$-> μμ: Analysis technique

DØ and CDF use similar method:

- Rate of B_s->μμ is measured relative to a control channel, B^+->$J/\psi K^+$, J/ψ->μμ
- Many systematic uncertainties cancel when taking the ratio

$$\mathcal{BR}(B_s \to \mu^+\mu^-) = \frac{N_{B_s}}{N_{B+}} \frac{\epsilon^{trig}_{B+}}{\epsilon^{trig}_{B_s}} \frac{\epsilon^{reco}_{B+}}{\epsilon^{reco}_{B_s}} \frac{\alpha_{B+}}{\alpha_{B_s}} \frac{1}{\epsilon^{NN}_{B_s}} \frac{f_u}{f_s} \cdot \mathcal{BR}(B^+ \to J/\Psi K^+ \to \mu^+\mu^- K^+)$$

From Data, From MC, From PDG

$$N_{B+} \approx 2 \times 10^4$$

$$\frac{\epsilon^{trig}_{B+}}{\epsilon^{trig}_{B_s}} \approx 1$$

$$\frac{\epsilon^{reco}_{B+}}{\epsilon^{reco}_{B_s}} \approx 1$$

$$\frac{\alpha_{B+}}{\alpha_{B_s}} \approx 0.5$$

$$\frac{1}{\epsilon^{NN}_{B_s}} \approx 1$$

$$\frac{f_u}{f_s} \approx 3$$

$$\mathcal{BR}(B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+) \approx 5 \times 10^{-5}$$

$B_{(s)}$-> μμ: Analysis technique

Blinded analysis

↓

Estimate efficiencies and acceptances

↓

Construct NN discriminant to reject background events

↓

Estimate remaining background

↓

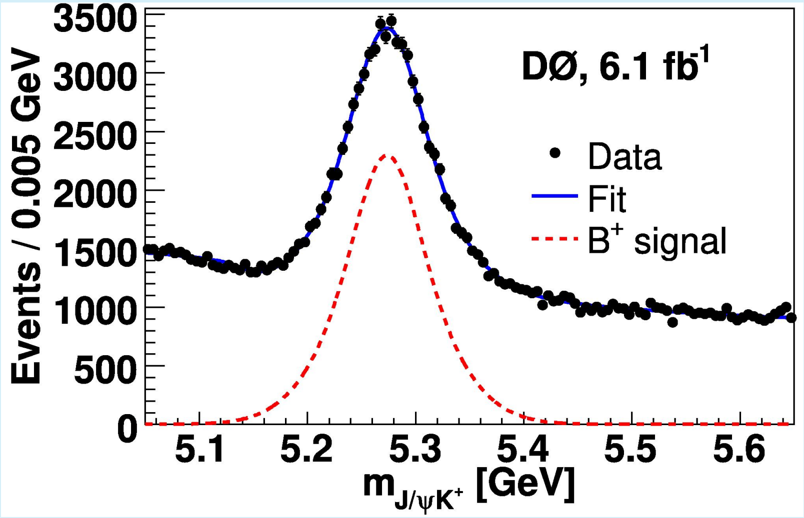
Unblind -> determine $\mathcal{BR}$ or limit

$B_{(s)}$-> μμ: Background rejection

Signal is fully reconstructed, long lived decay

Background can be made up of:

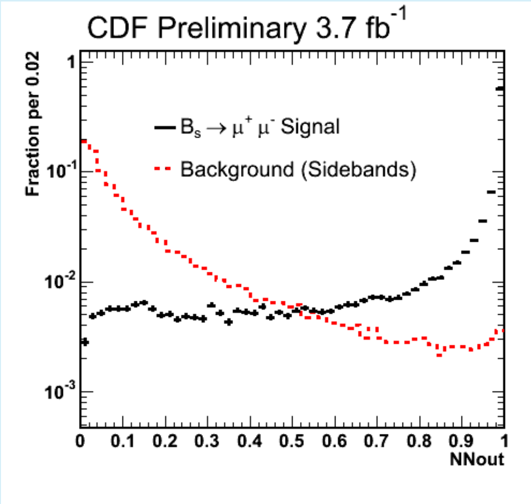
- Semi-leptonic decay:
  - *$b \to c\mu^- X \to \mu^+\mu^- Y$*
- Double semi-leptonic decay:
  - *$bb \to \mu^+\mu^- X$*
- *μ+fake, fake + fake*
- continuum $\mu^+\mu^-$
- *B->hadrons* (peaking in B mass signal region)



mass distribution of control sample

Background is generally softer, short lived, not fully reconstructed, more tracks

$B_{(s)}$-> $\mu\mu$: NN

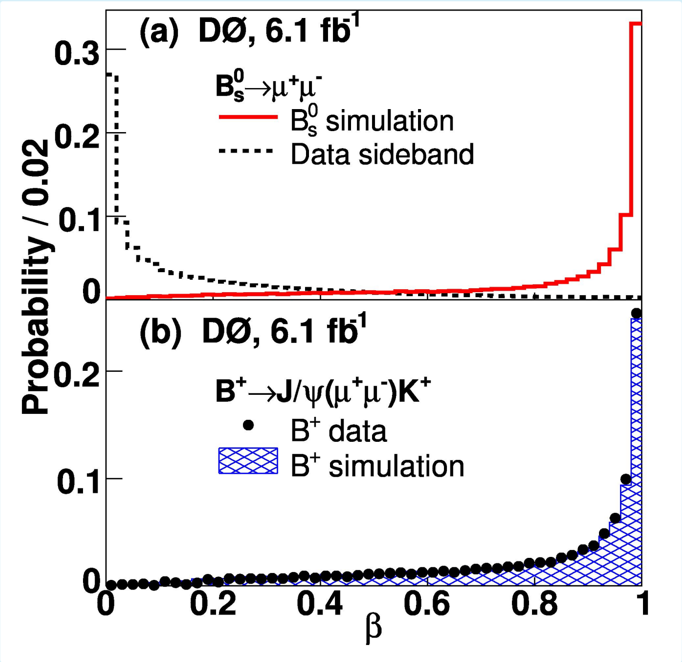


NN inputs: CDF

- secondary vertex length and angular variables
- isolation
- $p_T(B)$ and $\min(p_T^{\mu})$

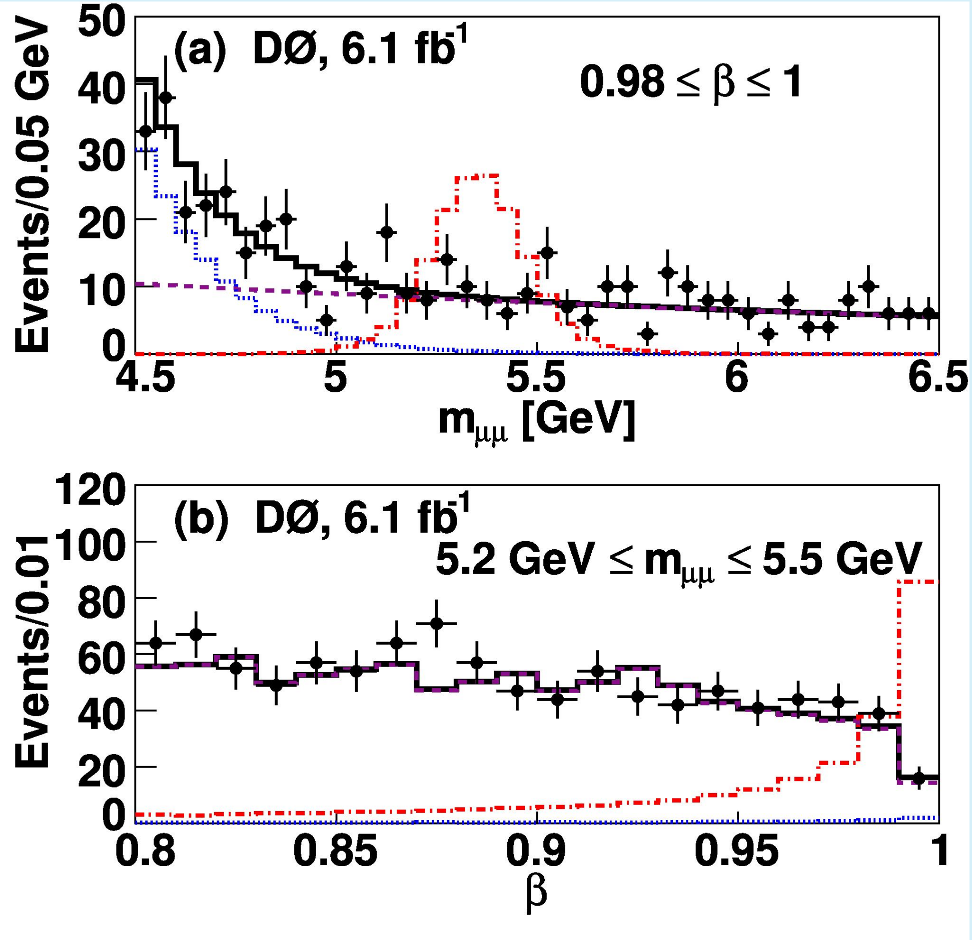
NN inputs: DØ

- L_T/σ_{LT}
- secondary vertex fit χ^2
- pointing angle
- p_T^B
- $\min(p_T^{\mu})$
- min μ impact parameter sig.



- NN trained on:
  - MC for signal sample
  - Side band data for background
- Extensive testing for mass bias
- 3 NN bins and 5 mass bins used to set limits for B_s and B_d

B_s-> μμ: DØ results



Red dashed line = SM signal x 100

At 95% CL:

$$\mathcal{BR}(B_s \to \mu^+\mu^-) < 5.1 \times 10^{-8}$$

- Expected bkg events in highest sensitivity region: 51 ± 4
- Observed events: 55

$B_{(s)}$-> μμ: CDF results

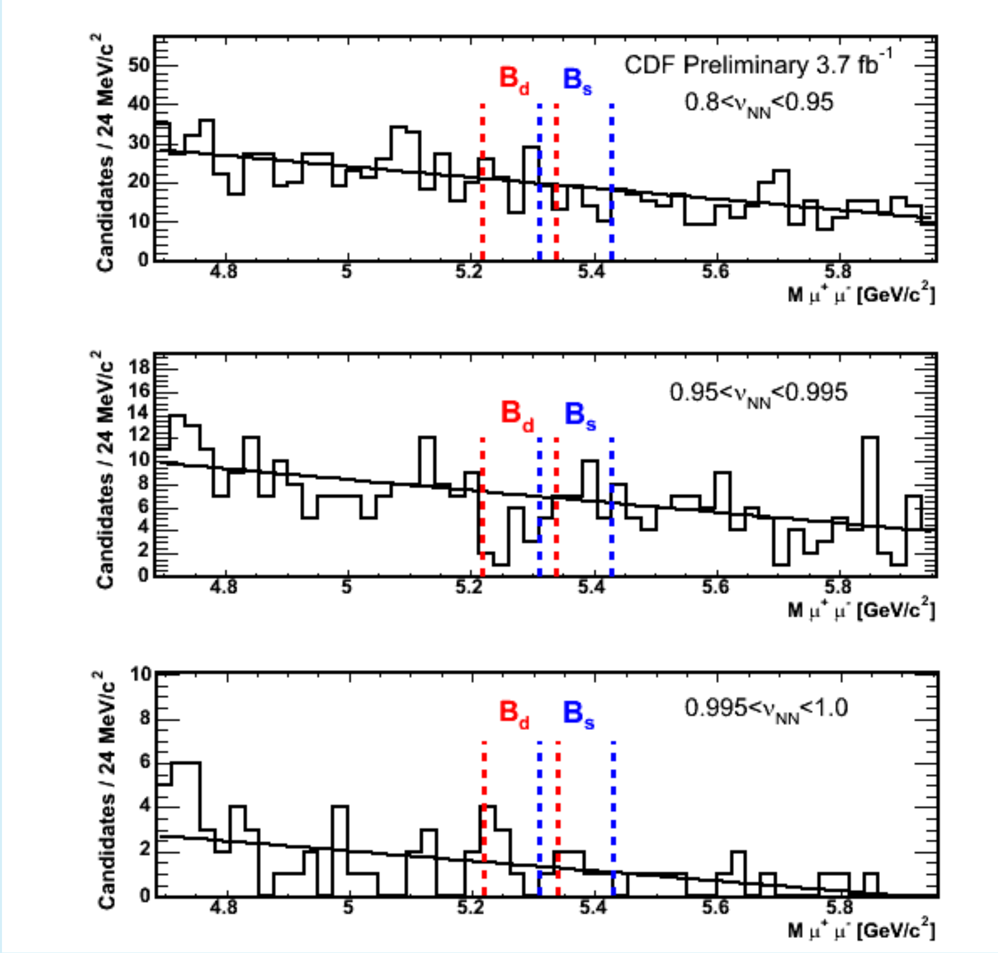
World's best limits
At 95% CL:

$$\mathcal{BR}(B_s \rightarrow \mu^+\mu^-) < 4.3 \times 10^{-8}$$

$$\mathcal{BR}(B_d \rightarrow \mu^+\mu^-) < 7.6 \times 10^{-9}$$

Events in signal region
($0.995<\nu_{NN}<1$)

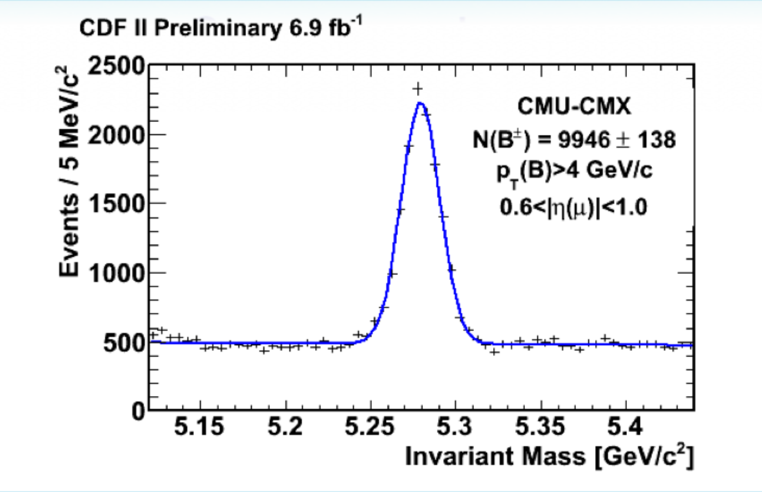
Channel	Expected	Observed
B_s Central	4.0±1.0	3
B_s Extended	2.1±0.8	4
B_d Central	5.3±1.0	5
B_d Extended	2.8±0.8	3



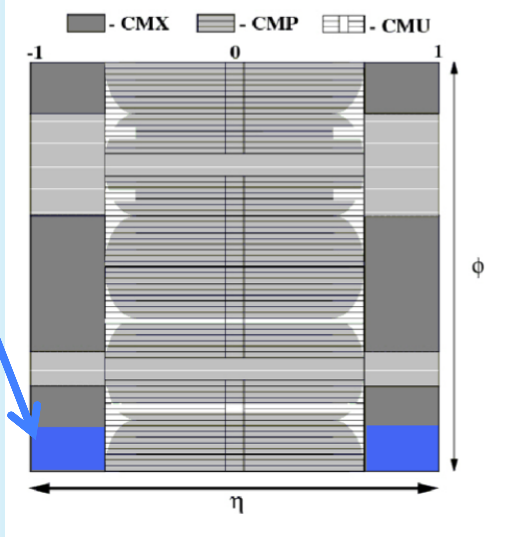
Signal windows in 3 NN bins with bkg fits superimposed

$B_{(s)}$-> μμ: coming soon from CDF…

Doubling data sample -> 7 fb^{-1}

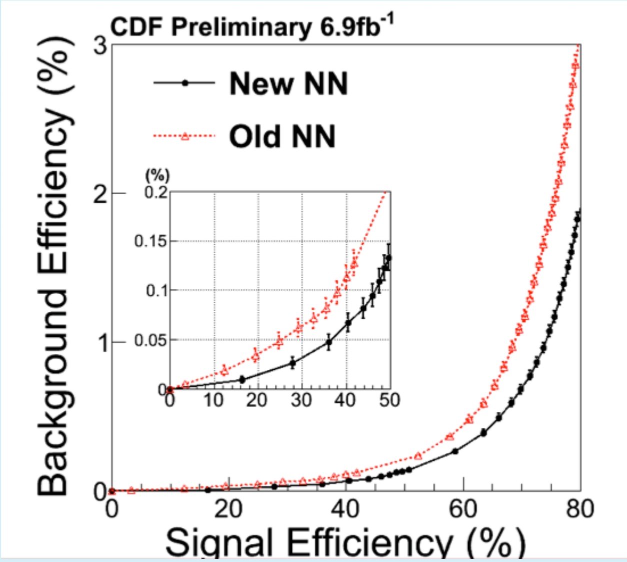


15% increase in muon acceptance



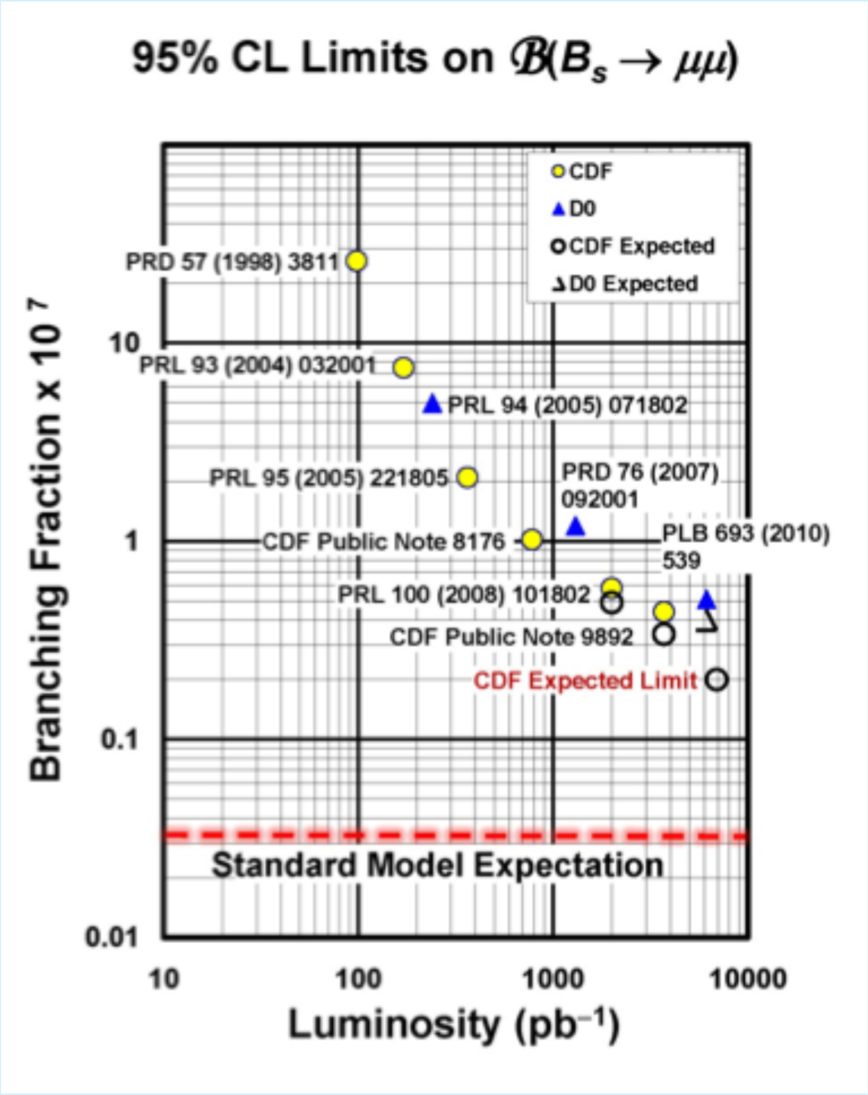
Improved NN signal efficiency:

- New 14 variable NN discriminator
- NN inputs carefully chosen to avoid bias in $M_{\mu\mu}$



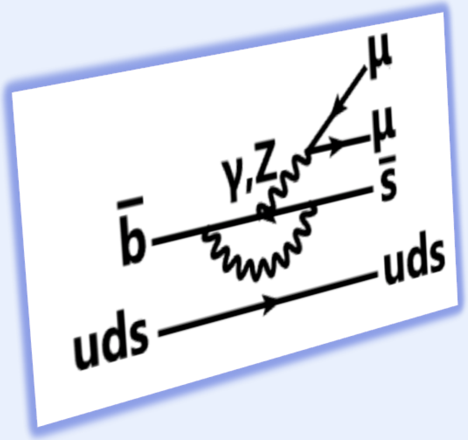
Better background predictions

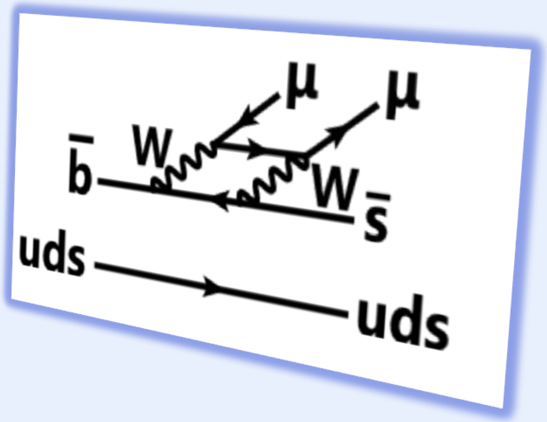
Expected $\mathcal{BR}(B_s\text{-> }\mu\mu)$ limits



CDF expected limit with 6.9 fb^{-1}: ~2×10^{-8}

b-> sll





- CDF: 4.4 fb^{-1} PRL 106, 161801 (2011)

Earlier publications:

- DØ: 0.45 fb^{-1} PRD 74, 031107(R) (2006)
- CDF: 0.92 fb^{-1} PRD 79, 011104(R) (2009)

$b \to sll$: Motivation

- Only occurs through FCNC mediated decays (in SM)
- *b-> sll* is sensitive to New Physics in the $M^2_{\mu\mu} = q^2$ dependence of
  - hadron polarization
  - F-B asymmetry
- Predicted SM branching ratio:

$$\mathcal{BR}(b \to s\mu^+\mu^-)10^{-6} - 10^{-7}$$

- Tevatron experiments competitive with *B* factories in *b-> sμμ* modes

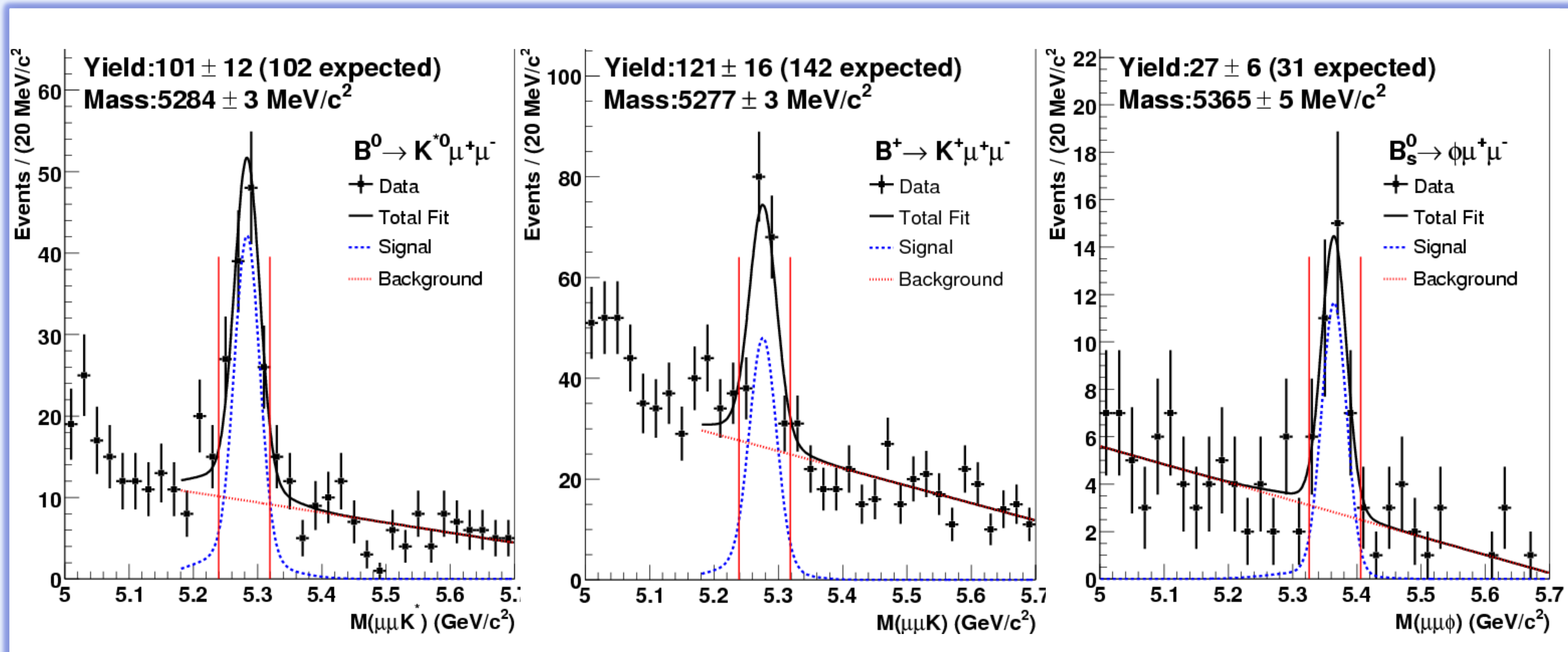
b -> sll: Analysis techniques

- Data collected with di-muon trigger
- Resonant modes *B->J/ψ X* used as control channel for non-resonant *b->sμμ*:

Signal Mode	Control Mode
$B^0 \to \mu^+\mu^- K^*$	$B^0 \to J/\Psi K^*$
$B^+ \to \mu^+\mu^- K^+$	$B^+ \to J/\Psi K^+$
$B_s \to \mu^+\mu^- \phi$	$B_s \to J/\Psi \phi$

- Pre-selection cuts and NN developed on signal channel, systematic effects checked on normalisation modes
- Veto applied on *μ* from *J/ψ, ψ'*
- *b->charm* and *b->charmless* backgrounds reduced by kinematic cuts
- Acceptance and efficiency corrections are calculated on MC and validated on control samples.

b -> sll: channels

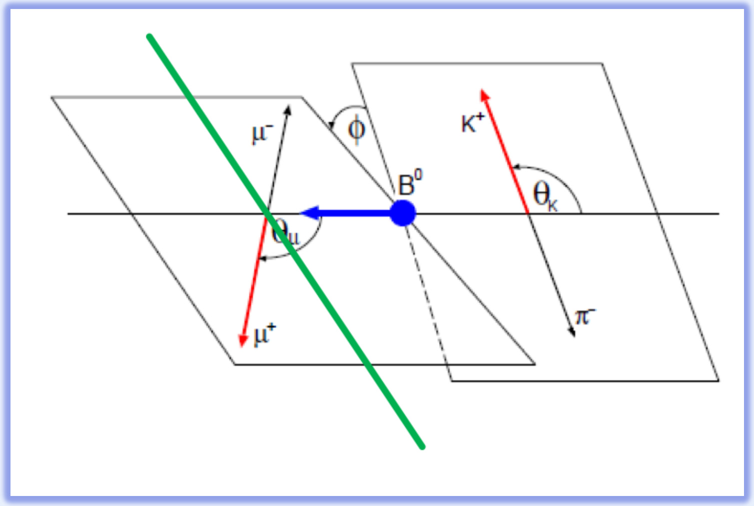


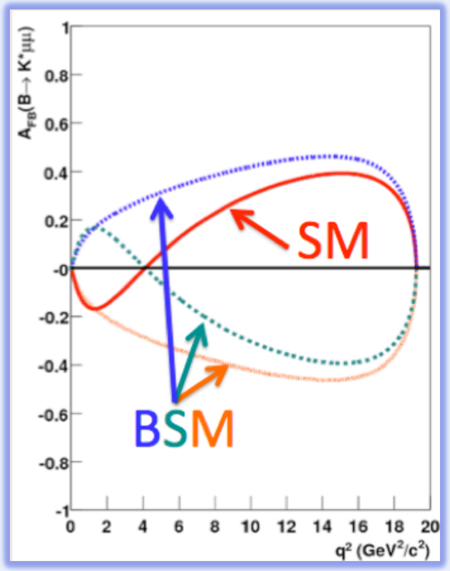
- First observation of $B_s \to \phi\mu^+\mu^- \sim 6\sigma$
- Measured branching ratio consistent with theoretical expectation of 1.61×10^{-6}

$$\mathcal{BR}(B_s \to \mu^+\mu^-\phi) = 1.44 \pm 0.33\ (\text{stat.})\ \pm\ 0.46(\text{syst.}) \times 10^{-6}$$

B^0-> $K^*\mu\mu$ and B^+-> K^+ $\mu\mu$: Angular analysis

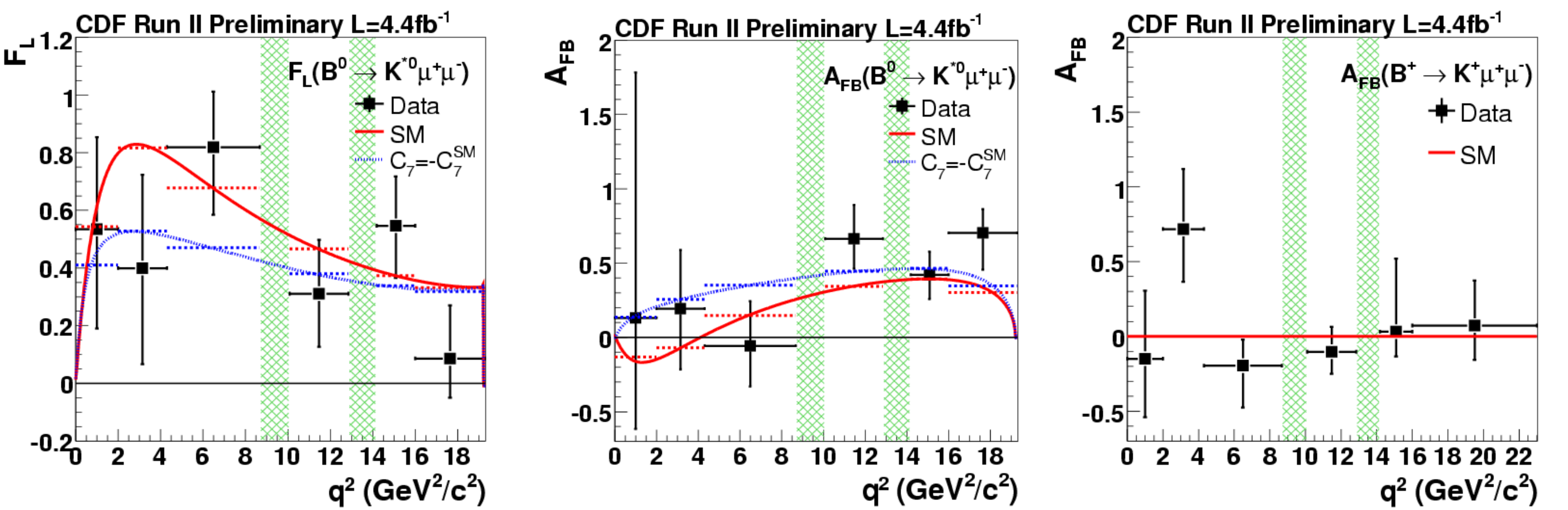
- Several BSM physics models predict A_{FB} in B^0->$K^*\mu\mu$
- Distinguishable from SM:
  - sign flips in Wilson Coefficients relative to SM





- Technique:
  - Data binned in 5 or 6 bins of di-muon mass squared (q^2)
  - A_{FB} measured from muon angular distribution in di-muon rest frame, using unbinned maximum likelihood fit
  - F_L (kaon longitudinal polarisation) measured from angular distribution of decay products in K^* rest frame

B^0-> $K^*\mu\mu$ and B^+-> K^+ $\mu\mu$: Angular analysis



Hatched regions are charmonium vetos

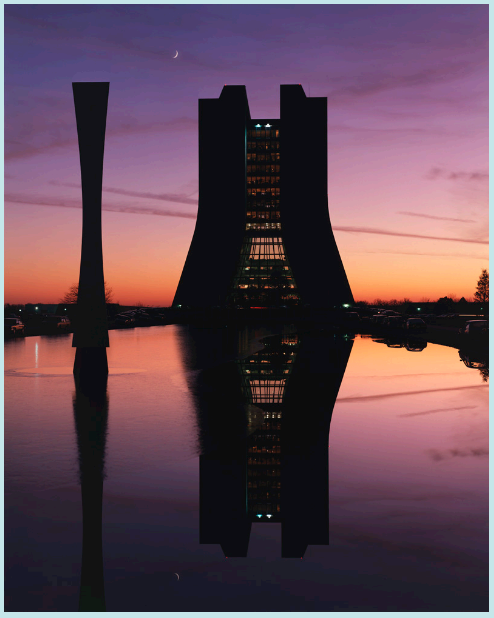
- Current data consistent with both SM and NP models

Summary

- Powerful test of New Physics models using FCNC decays $B_{(s)}\text{->}\mu\mu$ and *b->sll*
- CDF has World's best limits on $\mathcal{BR}$ of $B_{(s)}\text{->}\mu\mu$
- DØ and CDF are currently leading in rare B decay searches
- Updated and improved analysis of $B_{(s)}\text{->}\mu\mu$ with ~7 fb^{-1} in progress from CDF
- Results shown here use ~ half of the total dataset

→ Further important results yet to come from Tevatron experiments in these modes

Back up

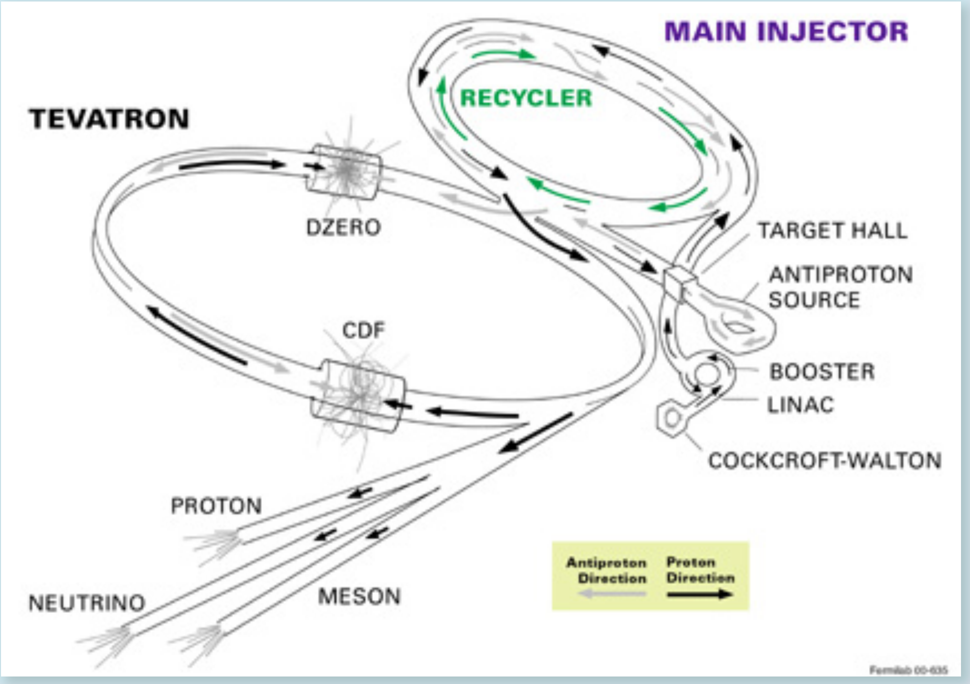


Overview

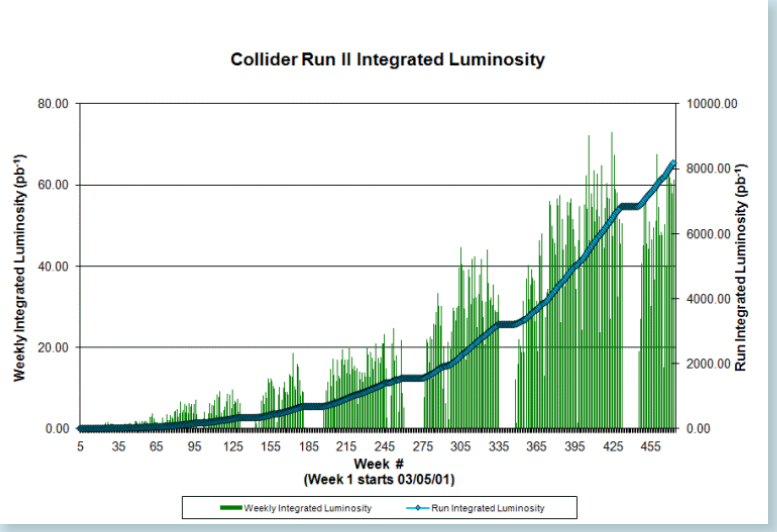
- Rare B decay channels:
  - $B_{(s)}\text{->}\mu\mu$
    - Motivation
    - Analysis technique
    - NN selection
    - Current Tevatron limits
    - Coming updates and expected limits
  - $B\text{->}h\mu\mu$
    - Motivation
    - Analysis technique
    - Latest results
- Summary

The Fermilab Tevatron

Tevatron performance



- p-pbar collisions at 1.96TeV
- Constantly improving luminosity performance
  - peak instantaneous luminosity >3x10^{32} cm^{-2}s^{-1}
  - ~10fb^{-1} delivered to the experiments

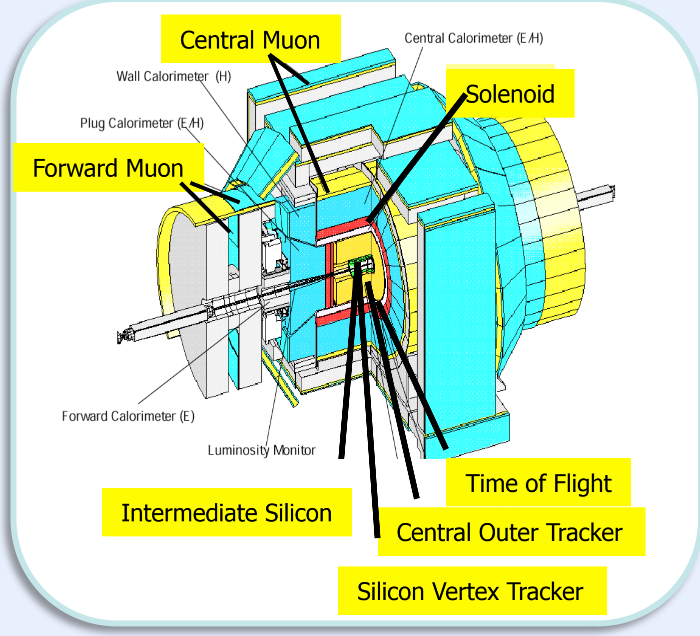


- High luminosity is a benefit but also a challenge for B physics
- Expect almost twice the current sample by end of run-II

Detectors

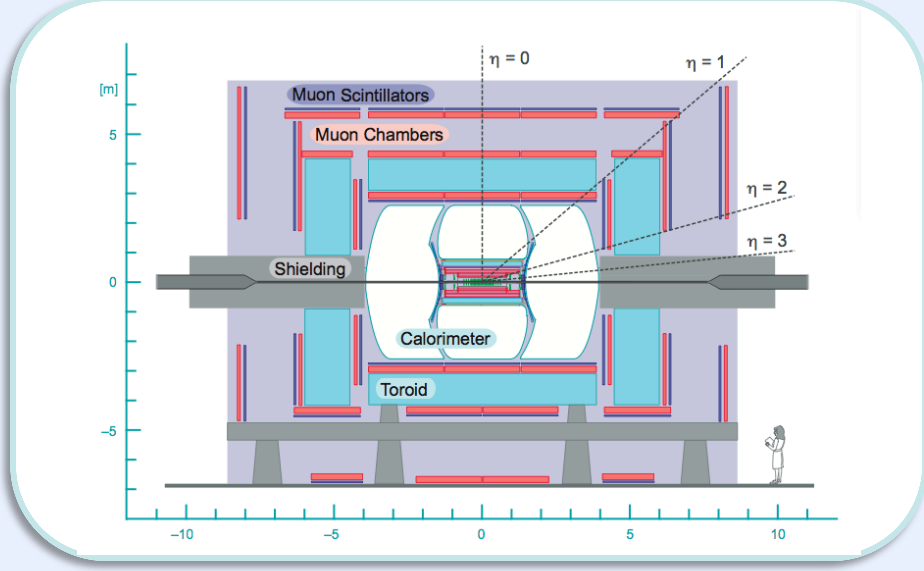
B physics at CDF:

- Particle ID: dE/dx and TOF
- Excellent vertex resolution ~23μm and p_T resolution: $\sigma(p_T)/p_T^2 \sim 0.1\ (\mathrm{GeV}/c)^{-1}$
- Trigger level silicon tracking



B physics at DØ:

- Solenoid (2TeV) polarity reversed weekly
- Strengths in semileptonic and J/ψ decays
- Excellent calorimetry and electron ID



Hadron colliders vs B factories:

\+ Much larger B production cross section, phase space, range of Bs generated

\- Higher background, don't know initial state

-> Larger signal for B_s at hadron machines but need sophisticated trigger and selection