New Results for Heavy Flavors and QCD tests at the Tevatron

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For CDF and D0 Collaborations

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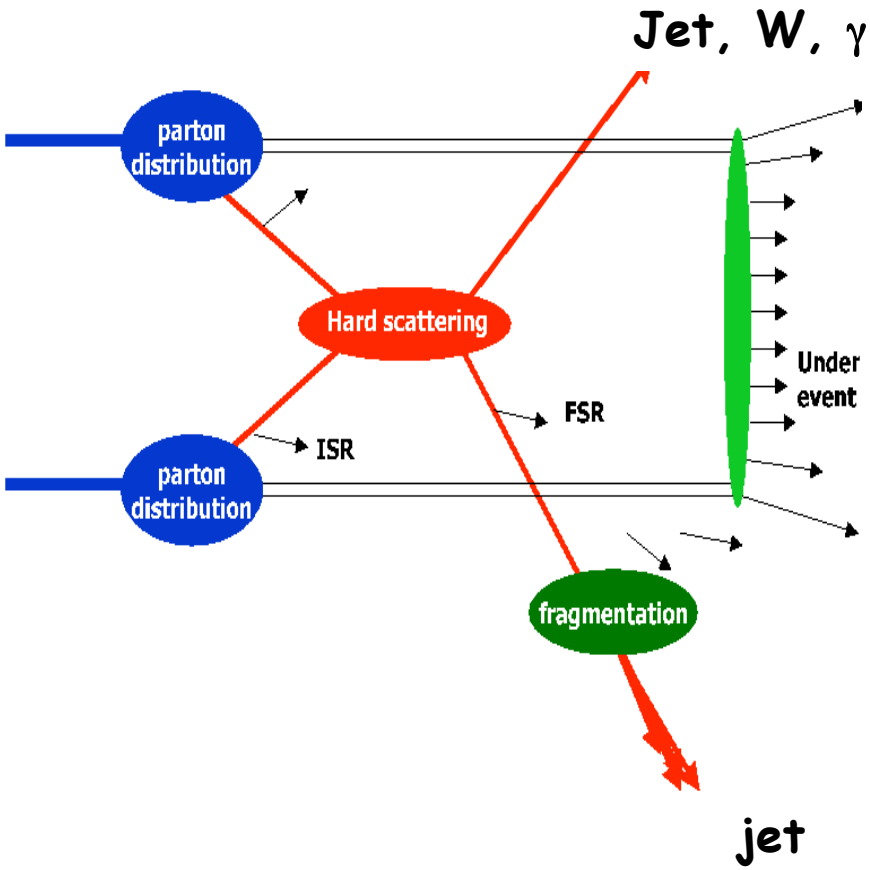
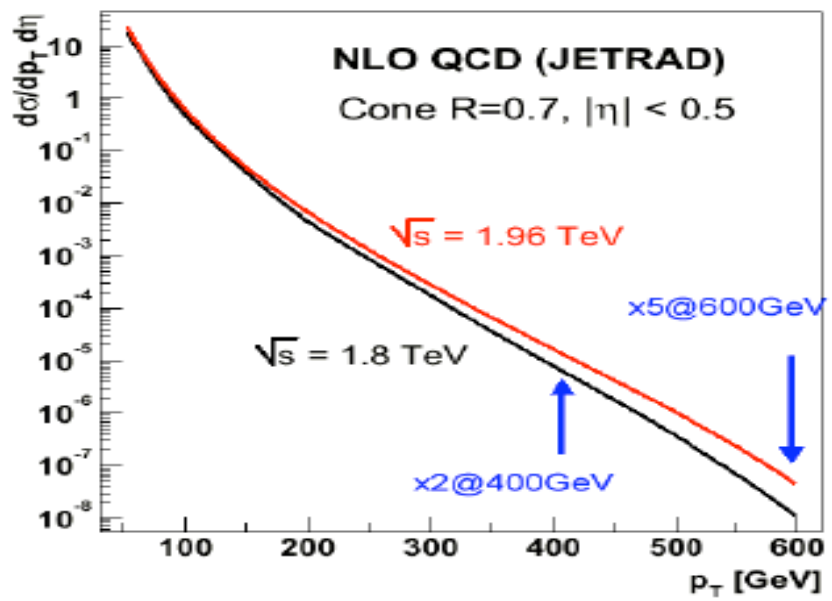
Outline:

- QCD: jets physics
- Heavy Flavor:
  - B Lifetimes and B_s Lifetime difference
  - Charmless B: Branching Ratios and CP Asymmetry
  - D^0 Branching Ratios and CP asymmetries
  - B excited states
  - B mixing

Jet Physics at 2 TeV

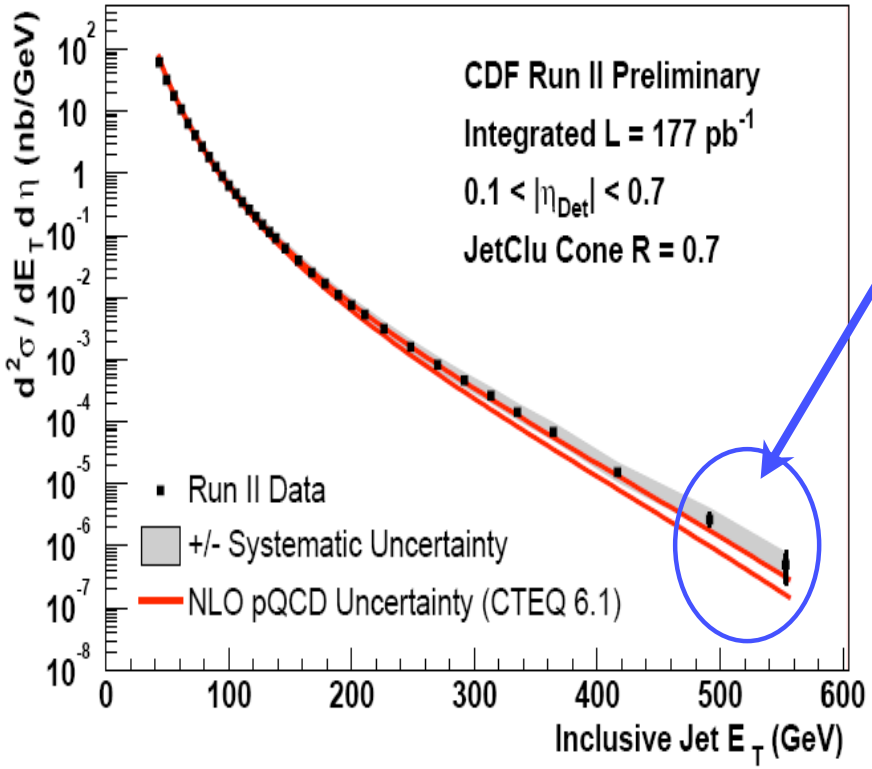


- Jet Cross Sections:
  - new physics and PDFs uncertainties @ high P_T
  - soft contribution @low P_T
- W + jet production
- B – jet production



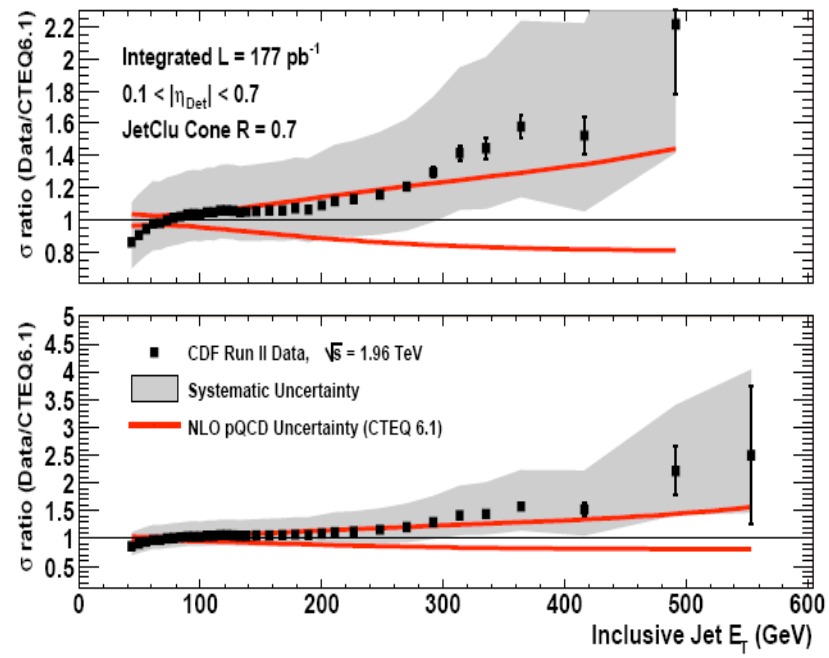
Why @ 2 TeV?
Big increase in cross section thanks to new $\sqrt{s}$

Inclusive Jet Cross section



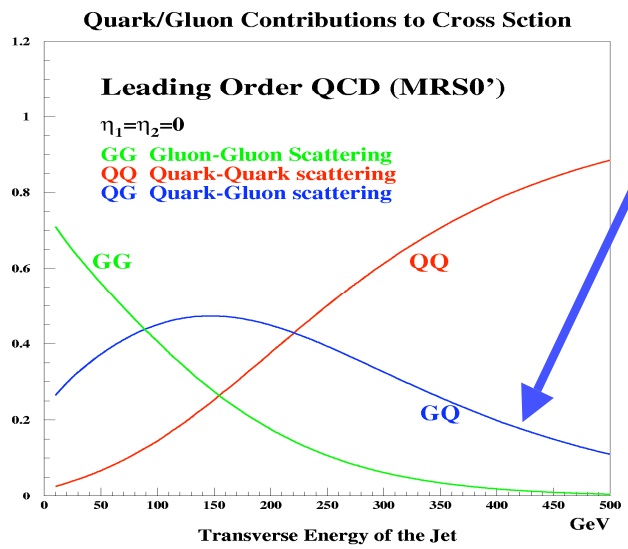
- Run I cone algorithm & unfolding
- E_T^{jet} range increased by ~150 GeV

Comparison with pQCD NLO
(over almost nine orders of magnitude)



Data dominated by jet energy scale
NLO error mainly from gluon at high x

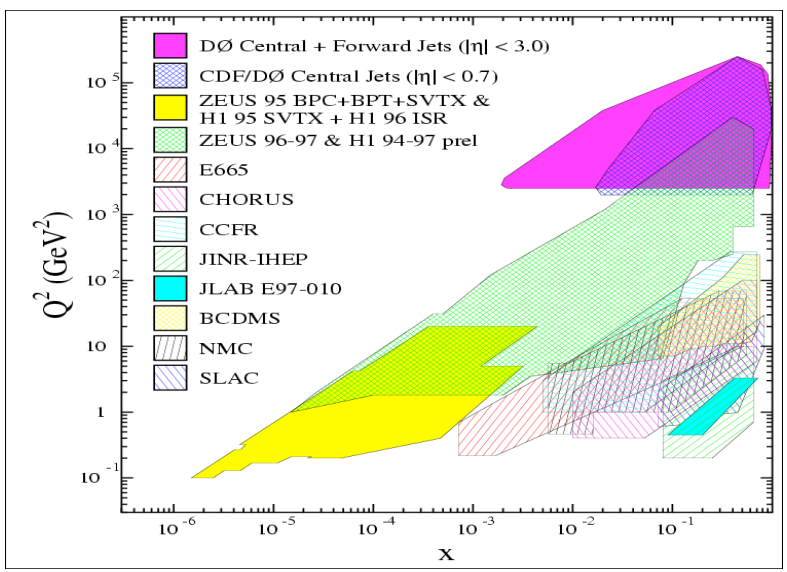
Inclusive Jet Cross section vs y

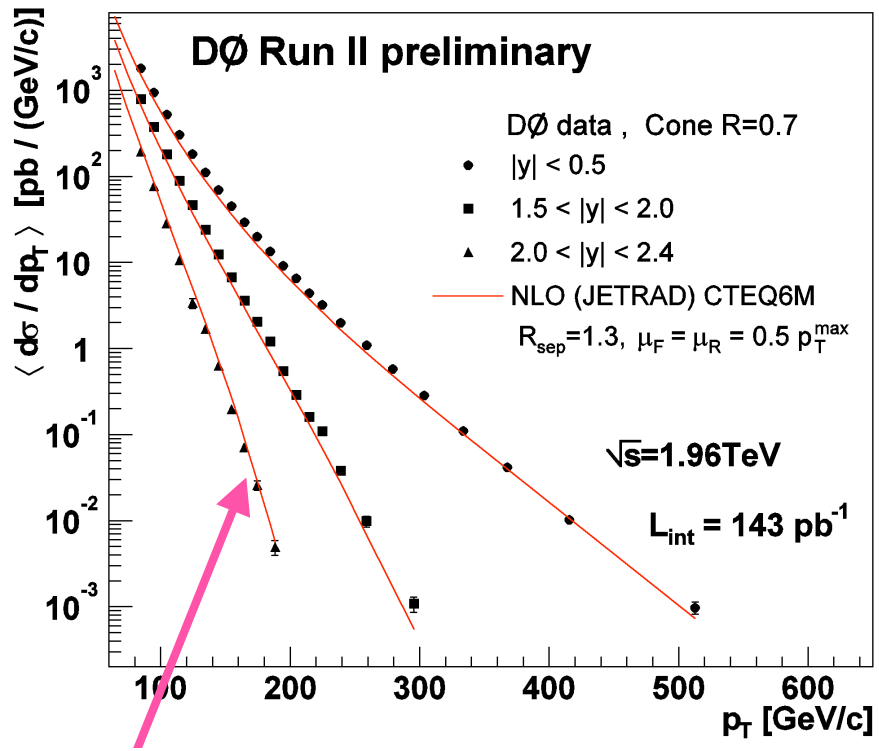


Important gluon-gluon and gluon-quark contributions at high- E_T

Gluon pdf at high-x not well known

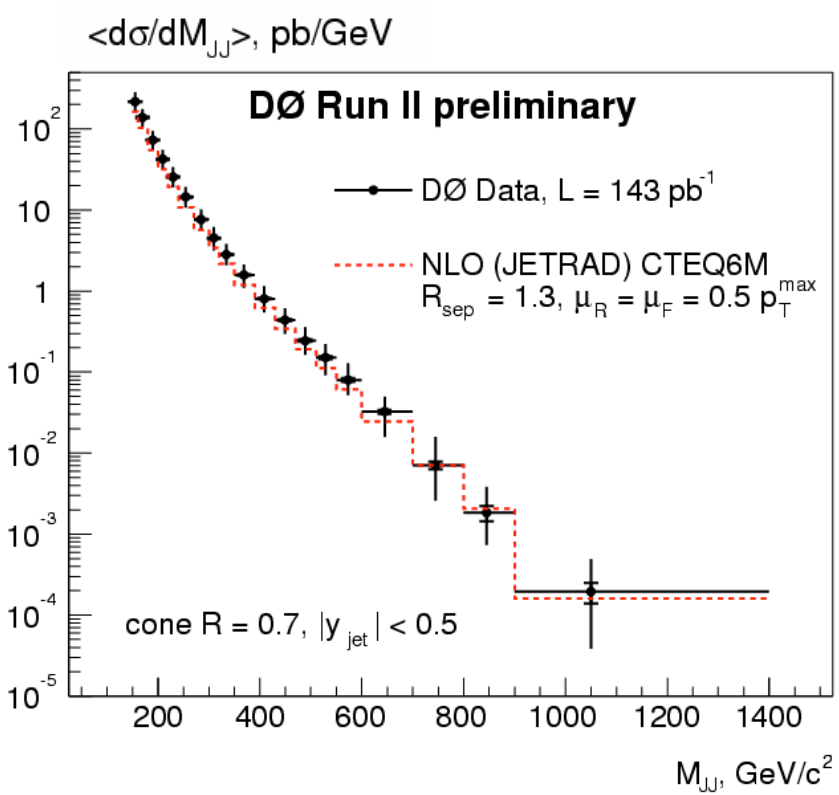
...room for SM explanation....

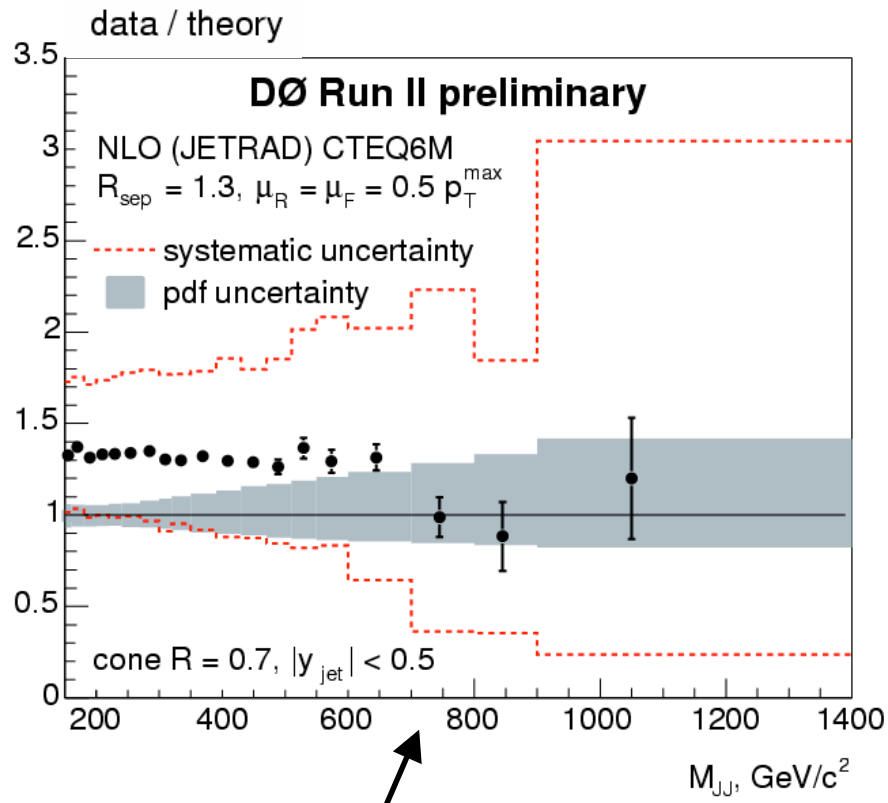




Constrain on gluon distribution at high x

Dijet Mass Cross section



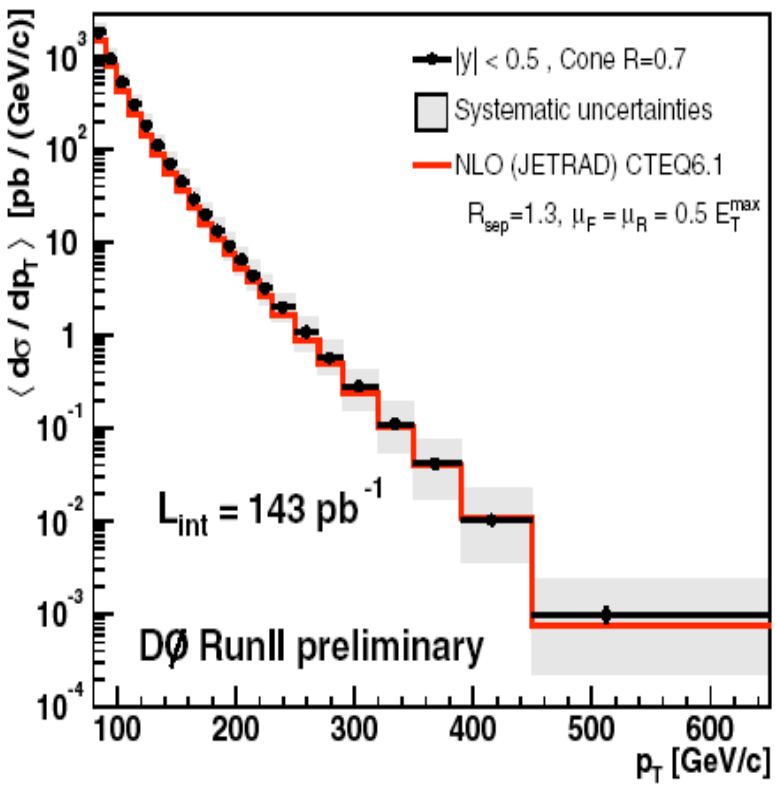


Resonances or excess at high mass:

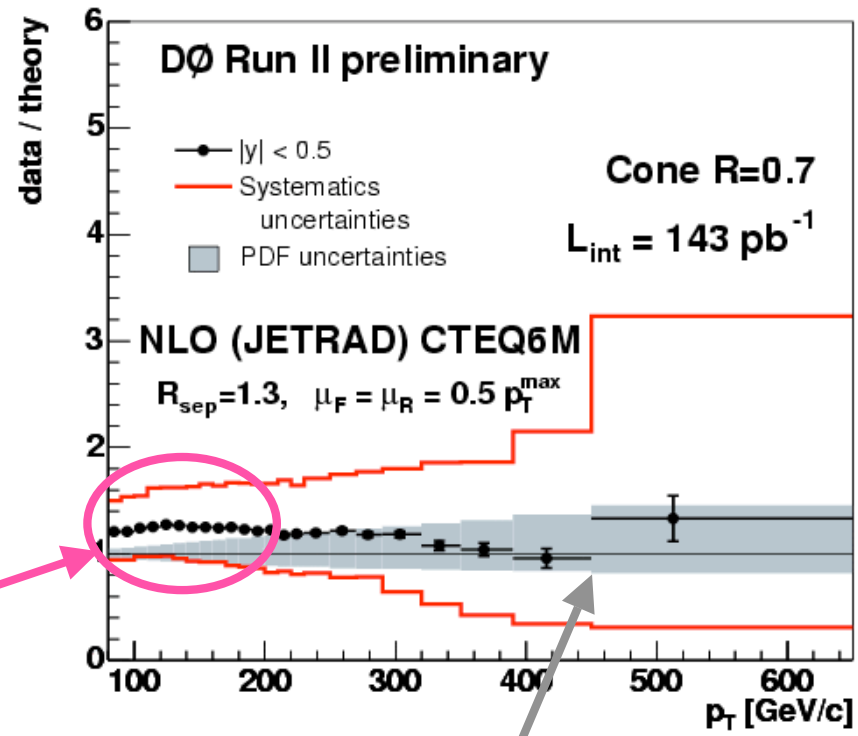
- new particles
- quark compositeness

data/theory agree within large systematic errors (mainly jet-energy scale)

Inclusive Jet P_T Cross section



Agreement with theory within systematic uncertainties (dominated by jet-energy scale)



Hadronization correction needed?

NLO uncertainty due to gluon @ high x

Inclusive Jet Cross section: K_T algorithm

- Inclusive K_T algorithm

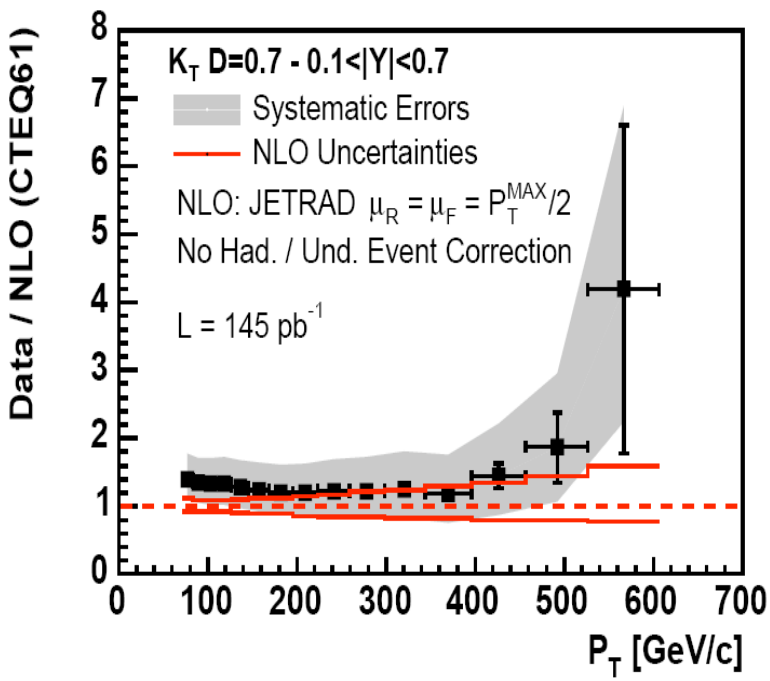
$$d_{ij} = \min(P^2_{T,i}, P^2_{T,j}) \frac{\Delta R^2}{D^2}$$

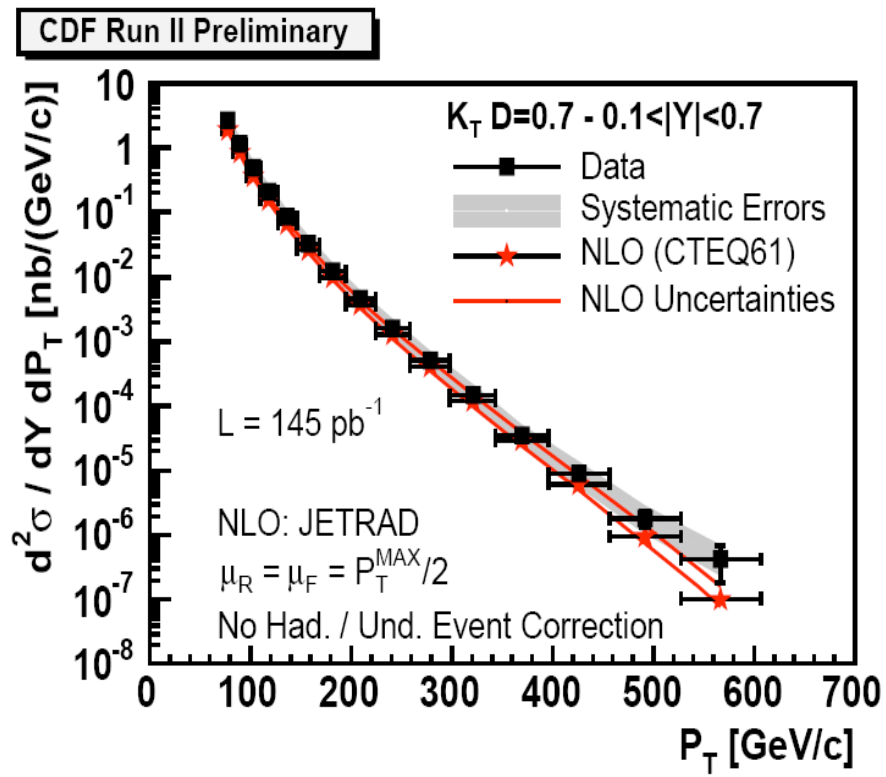
$\Delta R^2 \rightarrow (y_i - y_j)^2 + (\varphi_i + \varphi_j)^2$

$D^2 \rightarrow$ jet size

$$d_i = (P_{T,i})^2$$

- Infrared and collinear safe
- No merging / splitting





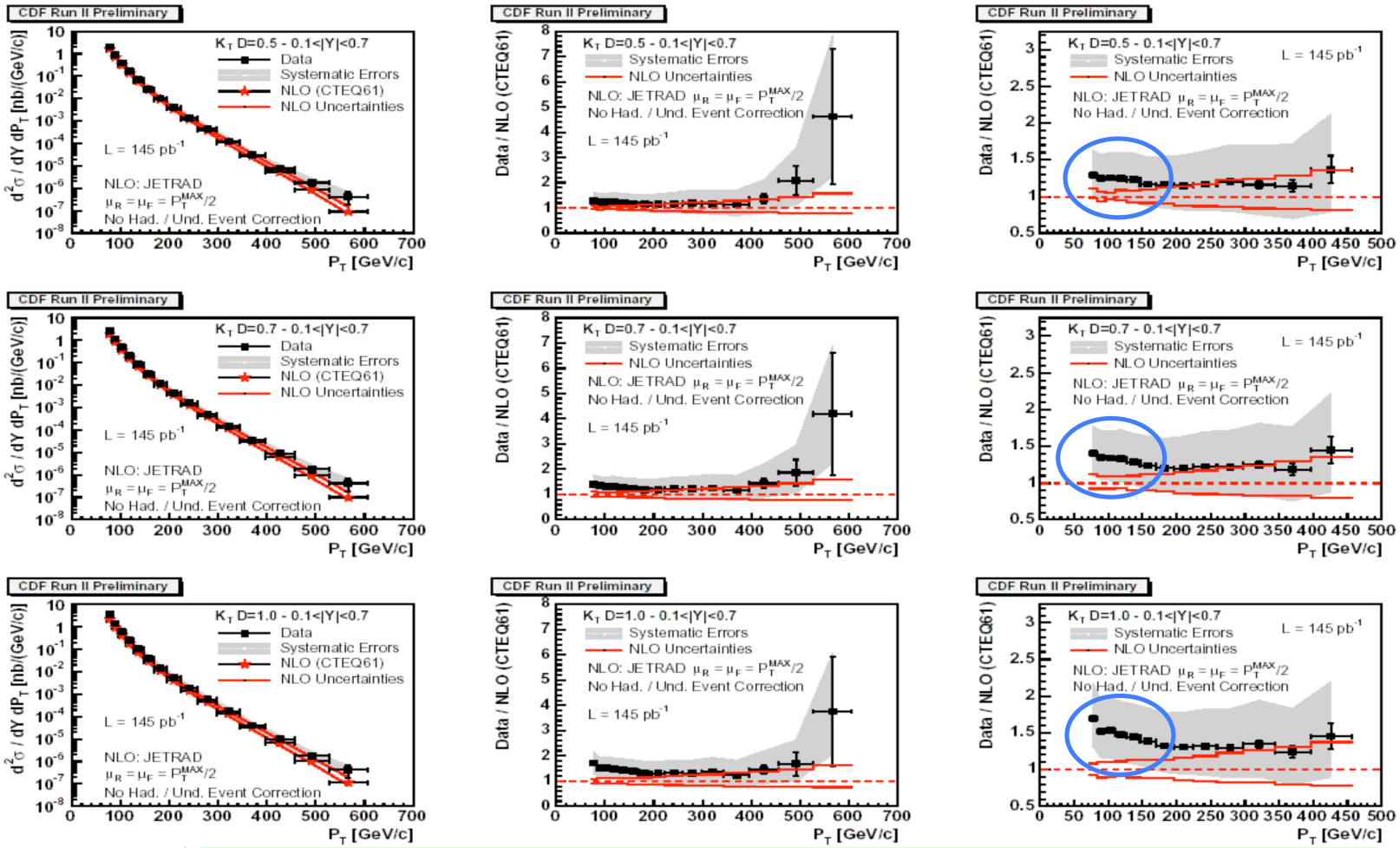
- Reasonable data-theory agreement
- NLO still needs to be corrected for Hadronization /Underlying Event

Inclusive Jet Cross Section K_T vs D

D=0.5

D=0.7

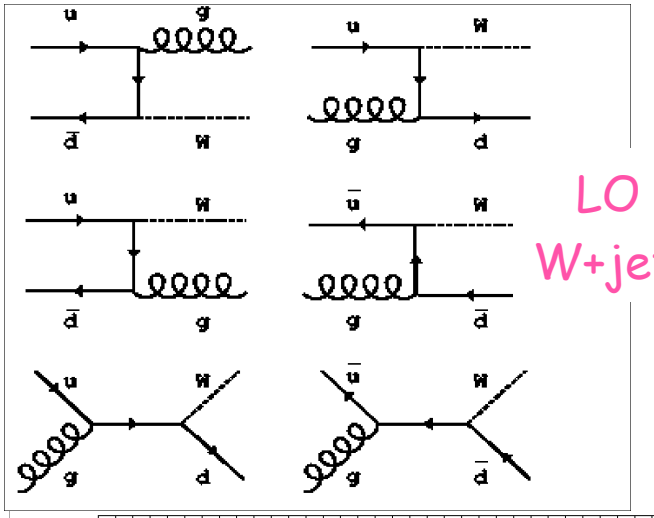
D=1



Frank Chlebana and Andrey Korytov talks for details

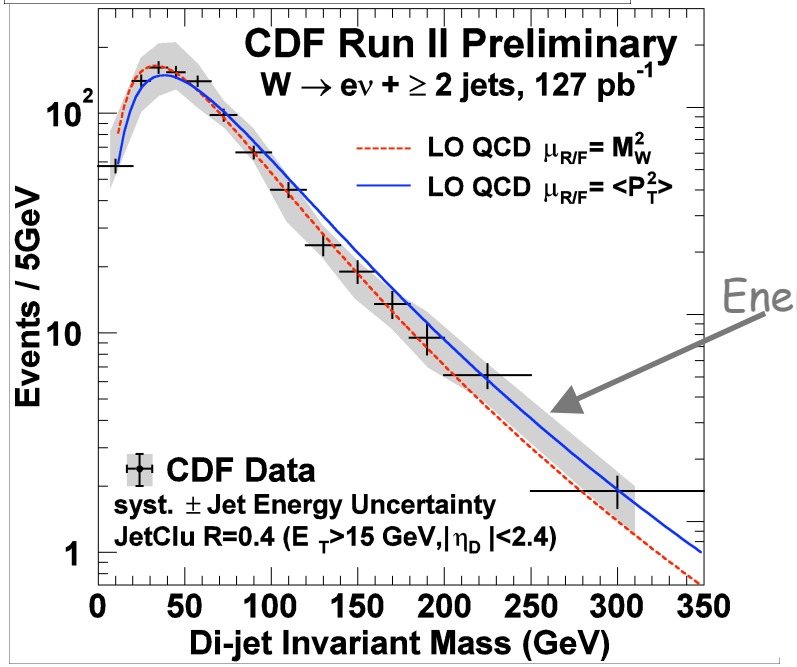
Increasing D data departs from pQCD NLO
⇒ more soft contributions

W + jets production

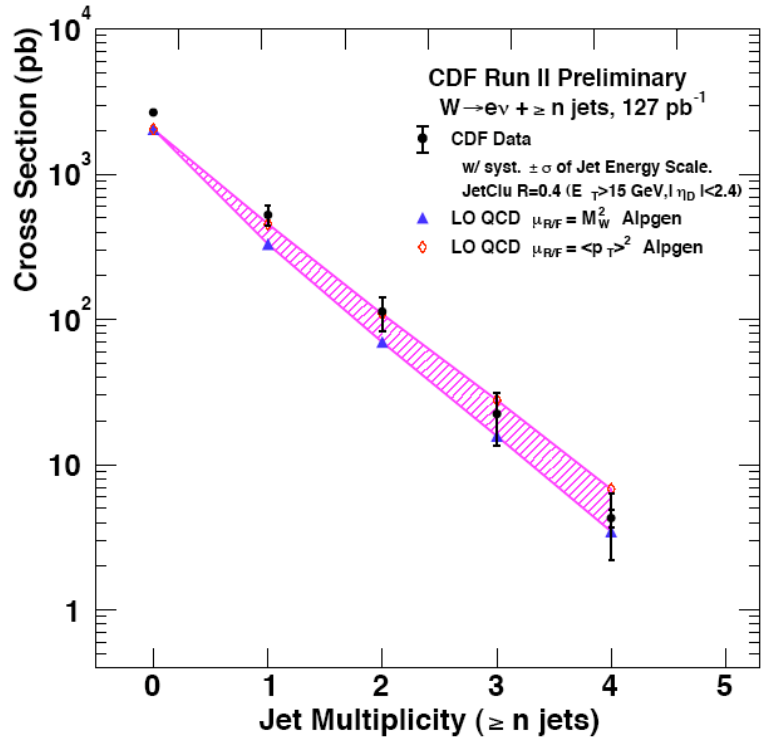


LO W+jets

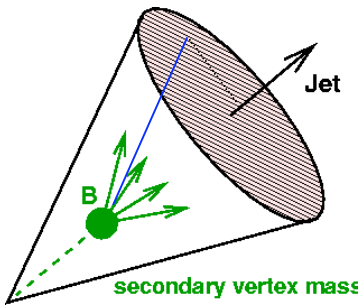
- Background to top and Higgs Physics
- Stringent test of pQCD predictions
- Test Ground for Matrix-Element + Parton Shower techniques (Alpgen Monte Carlo + Herwig Monte Carlo)



Energy scale



Heavy flavor production: B-jet

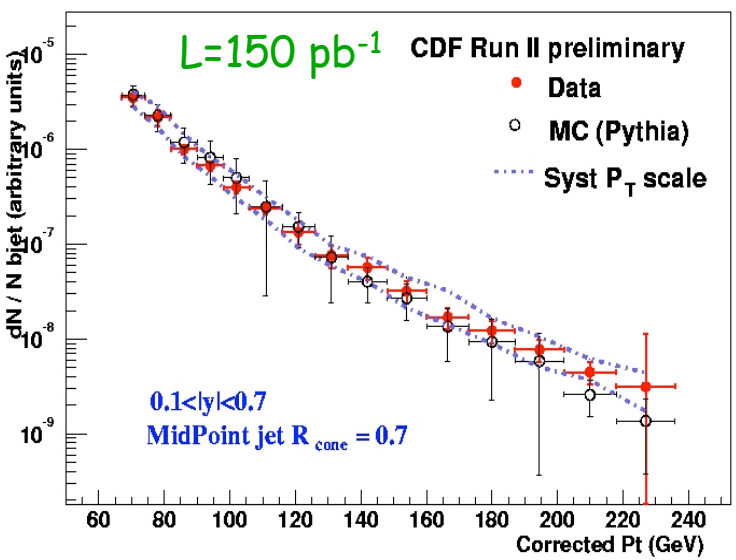


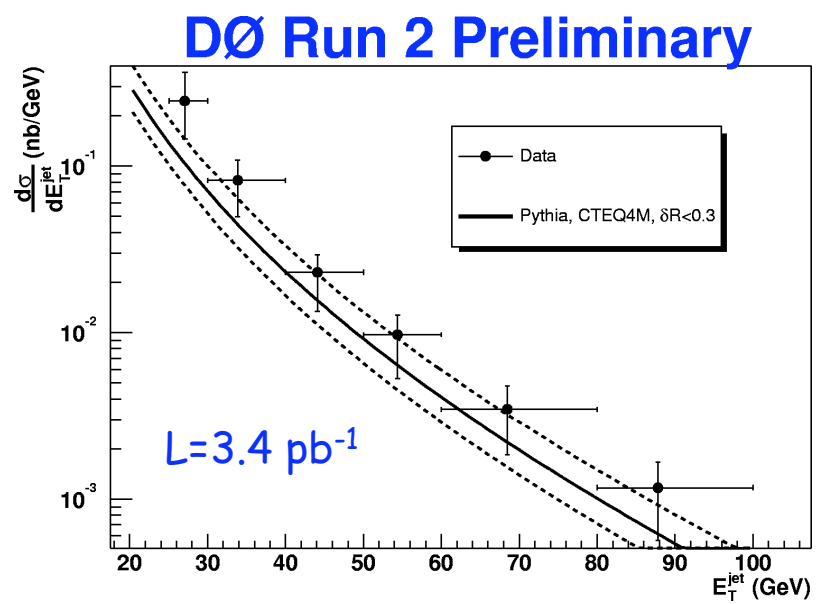
CDF:

- b-quark tagged using displaced secondary vertices
- invariant mass of tracks belonging to these vertices determines b fraction

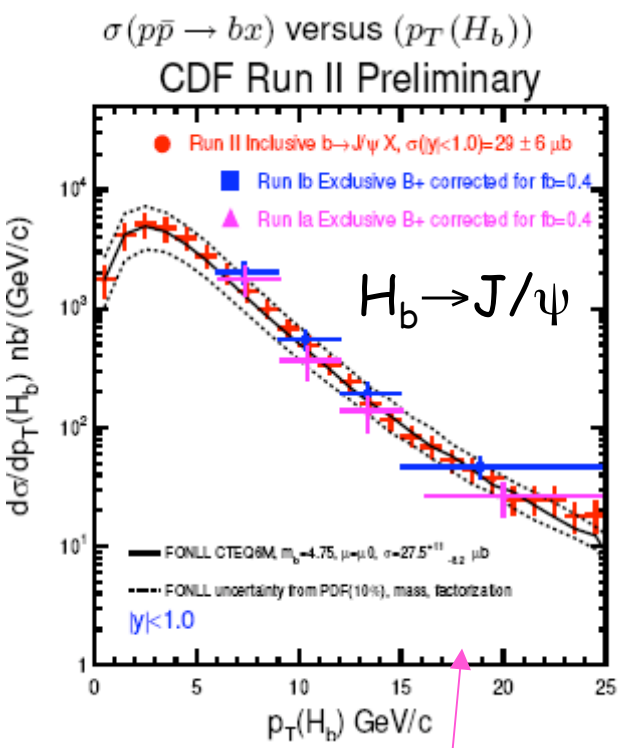
D0:

- muon+jets data
- b-tagging using p_T of muon relative to jet axis.

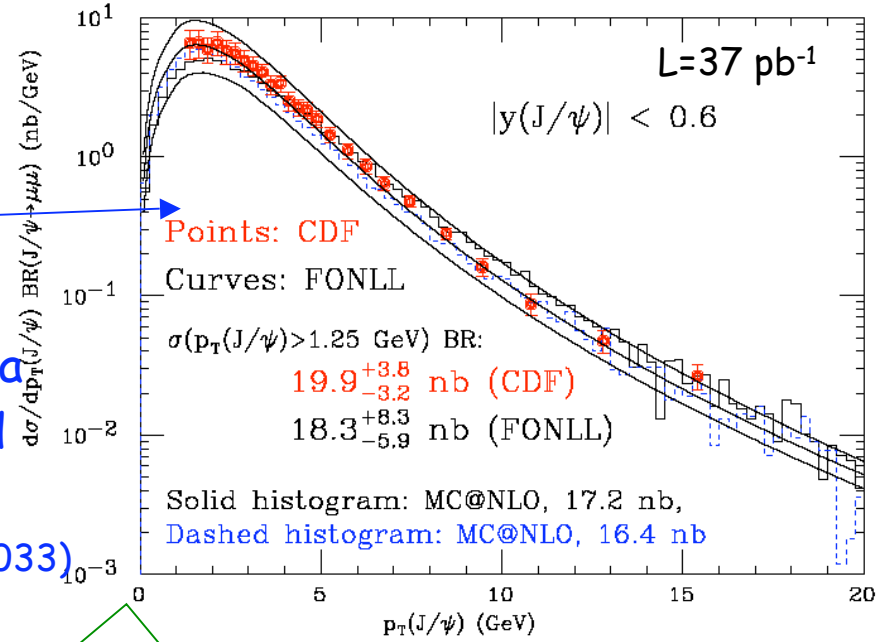




Beauty and Charm production at Tevatron



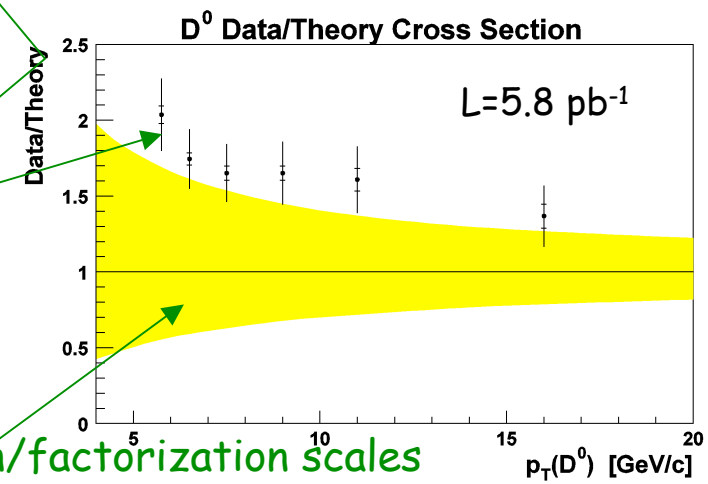
Cacciari, Frixione, Mangano, Nason, Ridolfi compared data to FONLL and MC@NLO: (JHEP07 (2004) 033)



Data: σ= 29 ± 6μb,
FONLL: σ=27.5
(CTEQ6M,m_b=4.75,$\mu=\mu_0$)

See Paul De Jong talk

$\sigma(p\bar{p} \to D^0 X, |y|<1.0, p_T>5.5$ GeV/c) = 13.3±0.2(stat.)±1.5(syst) μb



renormalization/factorization scales

B and D Physics at the Tevatron

- High cross sections + optimized trigger & detector $\Rightarrow$ possibility of high precision measurements
- All b-hadron and c-hadron species are produced
- Constrain the Standard Model and search for new physics:
  - B Lifetimes, B_s Lifetime difference
  - Branching Ratios and CP Asymmetries:
    - B decays
    - D decays
  - B^{**} states
  - B mixing

b-hadrons Lifetime

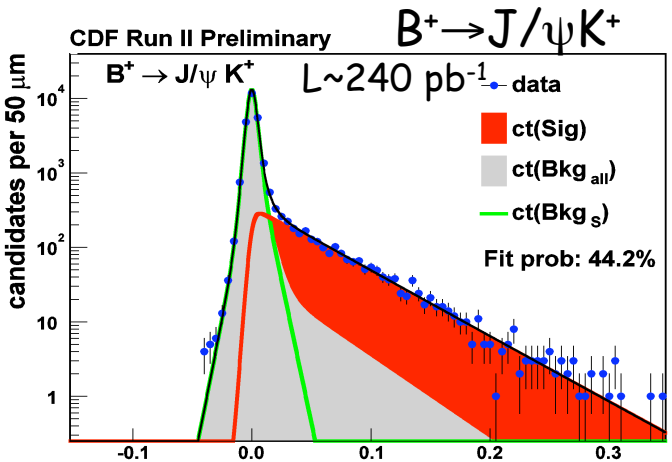
- Lifetime Ratios
  - test HQET QCD at NLO:

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.09 \pm 0.03 \qquad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.87 \pm 0.05 \qquad \frac{\tau(B_s)}{\tau(B_d)} = 1.00 \pm 0.01$$

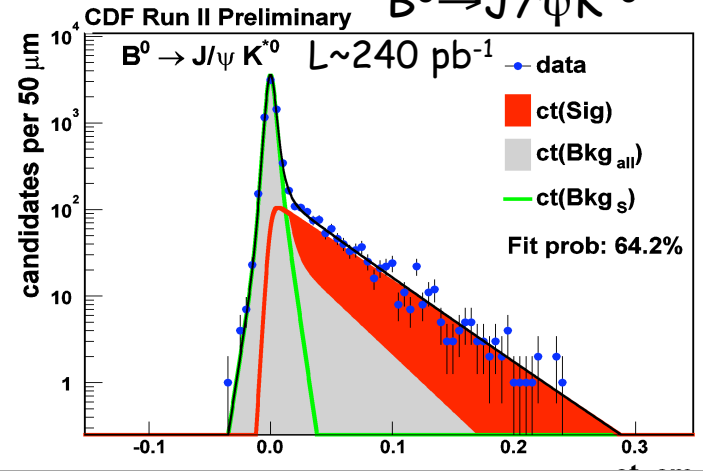
hep-ph/0407004

B^+/B^0 Lifetime Ratio Results

CDF

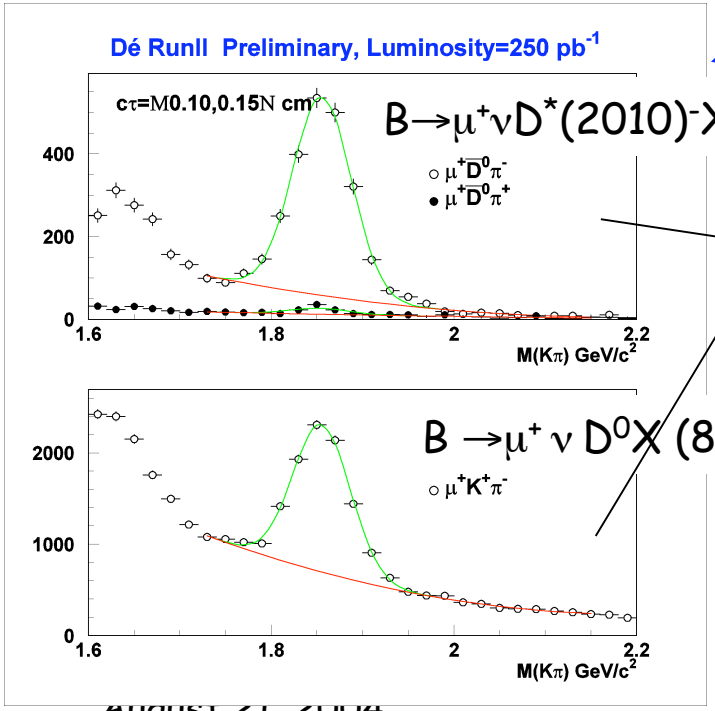


$B^0 \to J/\psi K^{*0}$

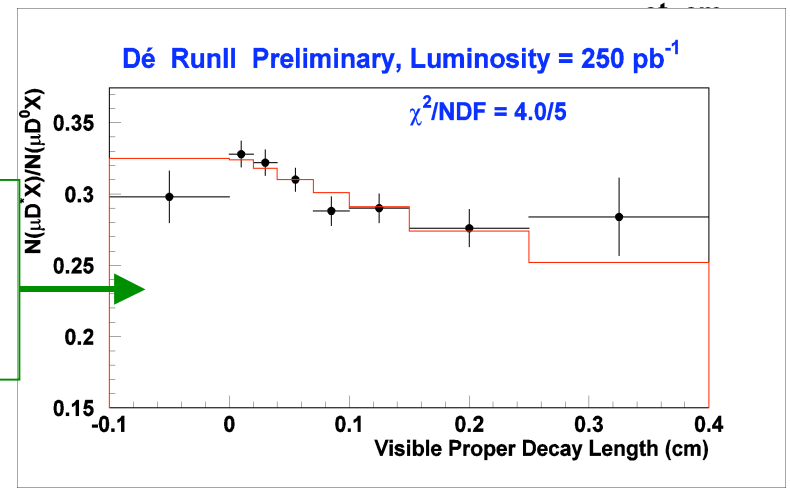


τ_{B^+}/τ_{B^0} :
1.080±0.042(tot.)

D0



ratio in bin of visible proper decay length

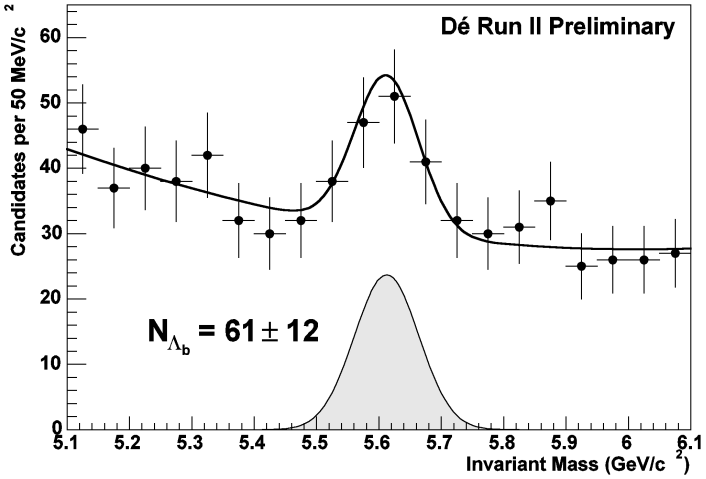


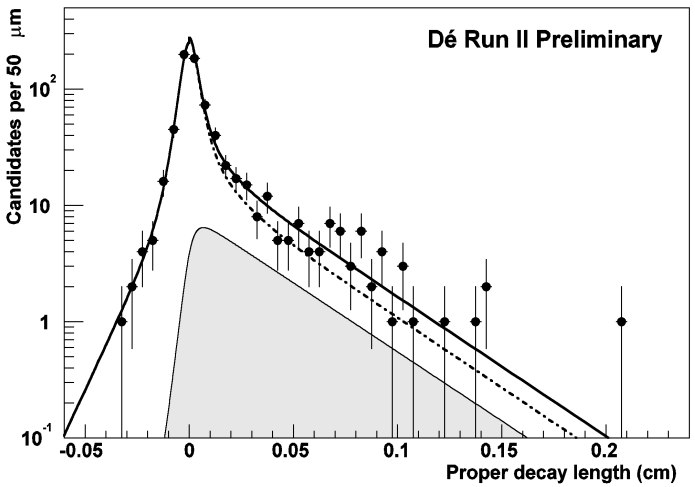
τ_{B^+}/τ_{B^0} : 1.093±0.021(stat.)±0.022(syst.)

τ_{B^+}/τ_{B^0} : 1.086±0.017(tot.) W.A.

Λ_b/B_d Lifetime Ratio

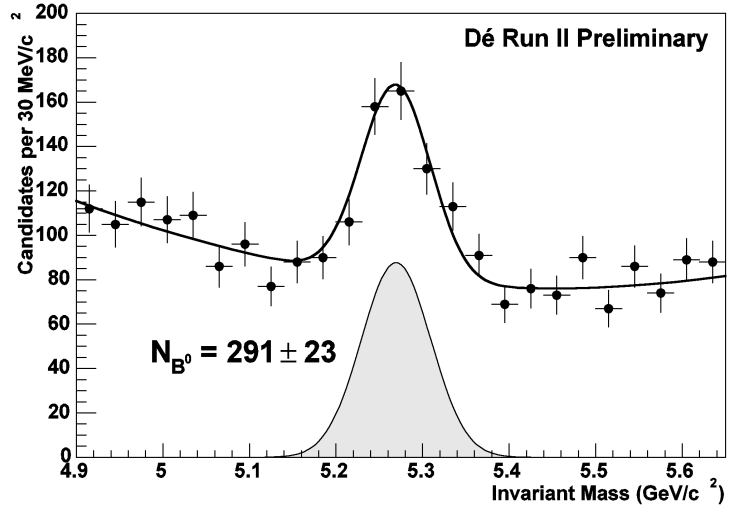
$\Lambda_b \rightarrow J/\psi \Lambda^0$





250 pb^{-1}

$B^0 \rightarrow J/\psi K^0_s$



$\tau_{B_d} = 1.397^{+0.107}_{-0.098}(\text{stat.}) \pm 0.031(\text{syst.})$

$\tau_{\Lambda_b} = 1.221^{+0.217}_{-0.179}(\text{stat.}) \pm 0.043(\text{syst.})$

$\tau_{\Lambda_b} = 1.229 \pm 0.080(\text{syst.})$ W.A.

$\tau_{\Lambda_b}/\tau_{B_d} = 0.874^{+0.169}_{-0.142}(\text{stat.}) \pm 0.028(\text{syst.})$

0.87±0.05 from theory

b-hadrons Lifetime

- Lifetime Ratios
  - test HQET QCD at NLO:

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.09 \pm 0.03 \qquad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.87 \pm 0.05 \qquad \frac{\tau(B_s)}{\tau(B_d)} = 1.00 \pm 0.01$$

hep-ph/0407004

- B_s Lifetime Difference
  - $\Delta m = m_H - m_L \geq 0$ and $\Delta\Gamma = \Gamma_L - \Gamma_H \geq 0$
  - SM expectation: $\Delta\Gamma_{Bs}/\Gamma_{Bs} \sim (7\text{-}14)\times 10^{-2}$
  - Indirect Δm_s measurement (model dependent):

$$\frac{\Delta\Gamma_{B_s}}{\Delta m_s} = 3.9^{+0.8}_{-1.5}\, x 10^{-3}$$

Fermilab-Pub-01, 197

  - $B_s \rightarrow J/\psi\phi$: Pseudoscalar$\rightarrow$Vector-Vector
  - Decay amplitude: 3 linear polarization states
  - $B_{s,Light} \approx$ CP even, $B_{s,Heavy} \approx$ CP odd (different angular distribution)

B_s Lifetime difference: $B_s^0 \to J/\psi\phi$

D0 result ready soon !!

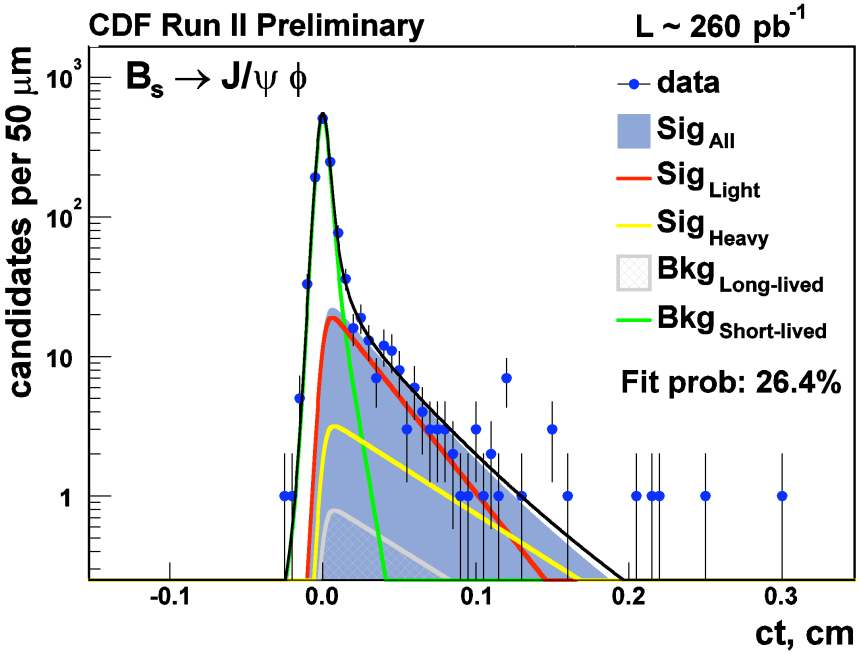
Fit the decay rate as function of A_0, $A_{||}$, $A_\perp$, Γ_L, $\Delta\Gamma$

B^0

$A_0 = 0.750 \pm 0.017 \pm 0.012$ $\quad A_{||} = (0.473 \pm 0.034 \pm 0.006)e^{(2.86 \pm 0.22 \pm 0.07)i}$

$|A_\perp| = (0.464 \pm 0.035 \pm 0.007)e^{(0.15 \pm 0.15 \pm 0.04)i}$ $\quad \tau_{B0} = 1.54 \pm 0.05 \pm 0.02$ ps

Consistent with B factories results



B^0_s

$A_0 = 0.784 \pm 0.039 \pm 0.007$

$A_{||} = (0.510 \pm 0.082 \pm 0.013)e^{(1.94 \pm 0.36 \pm 0.03)i}$

$|A_\perp| = (0.354 \pm 0.098 \pm 0.003)$

$\Delta\Gamma = 0.47\ ^{+0.25}_{-0.33} \pm 0.01$ ps^{-1}

$\Delta\Gamma/\Gamma = 0.65\ ^{+0.19}_{-0.24} \pm 0.01$

$\Delta\Gamma/\Gamma = 0$ excluded with P = 1/315

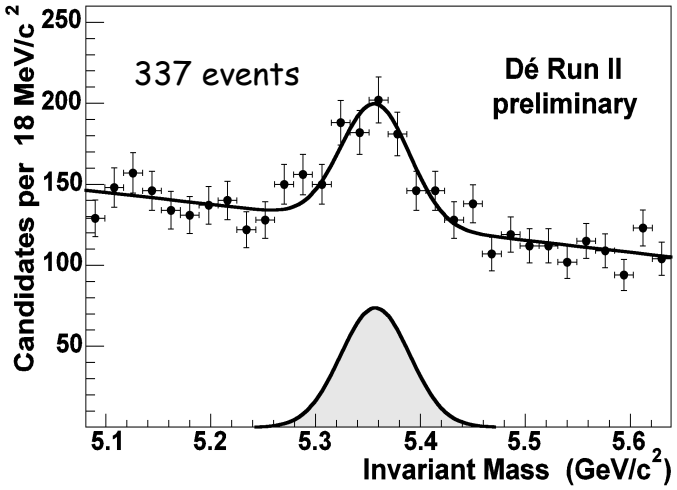
$\Delta\Gamma/\Gamma = 12$ excluded with P = 1/84

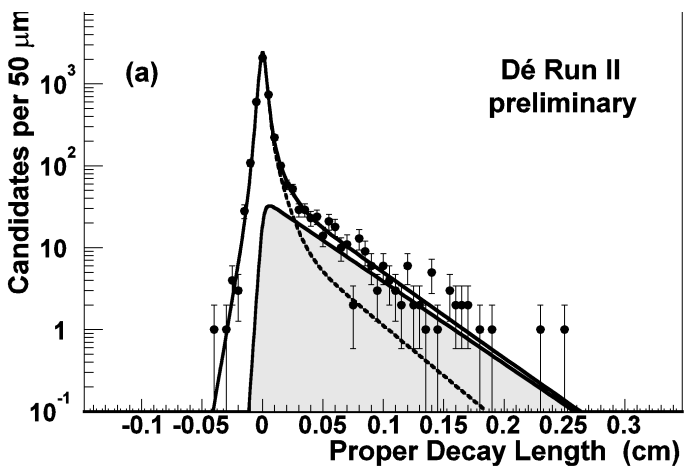
$\Delta\Gamma/\Gamma = 0.71\ ^{+0.24}_{-0.28} \pm 0.01$

with $\Gamma_s = \Gamma_d$ constraint

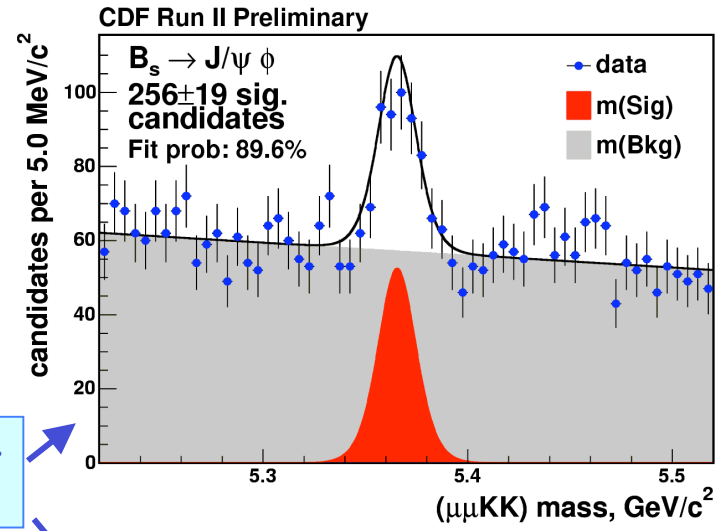
$\Delta\Gamma_s$ results $\Delta m_s = 125\ ^{+69}_{-55}$

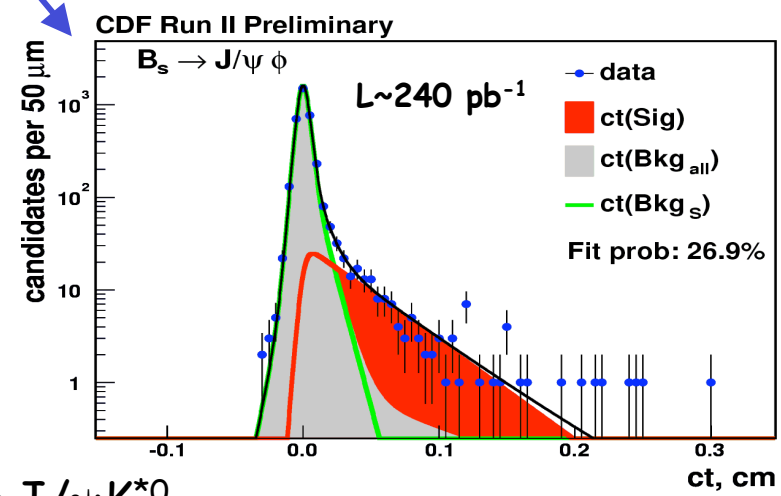
B^0_s Lifetime: $B_s^0 \to J/\psi\phi$ one component





D0 CDF





Ratio respect to $B_d^0 \to J/\psi K^{*0}$

$\tau_s/\tau_d = 0.980^{+0.075}_{-0.070}(\text{stat.}) \pm 0.003(\text{syst.})$ $\tau_s/\tau_d = 0.890 \pm 0.072(\text{tot.})$

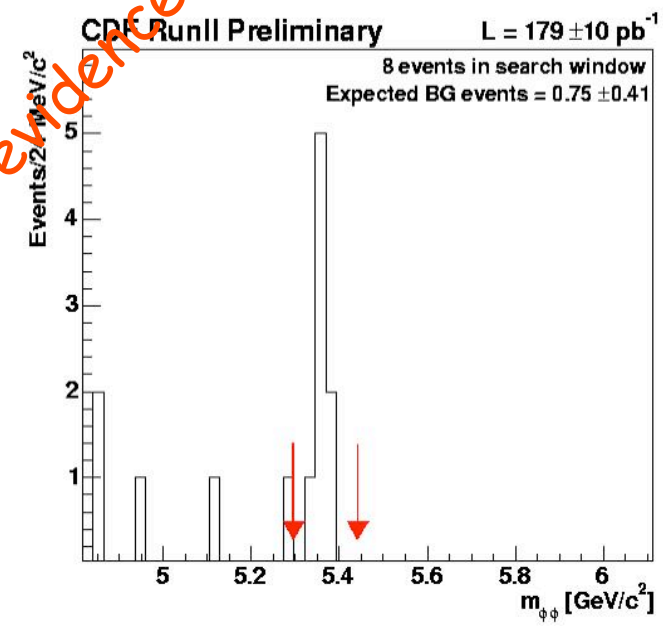
Charmless B Decays

Charmless $B_s \to \phi\phi$

Marco Rescigno presentation

- Measure $\Delta\Gamma$
- Extract information on α and γ
- Direct $\not{CP}$ small $\Rightarrow$ test SM

First evidence



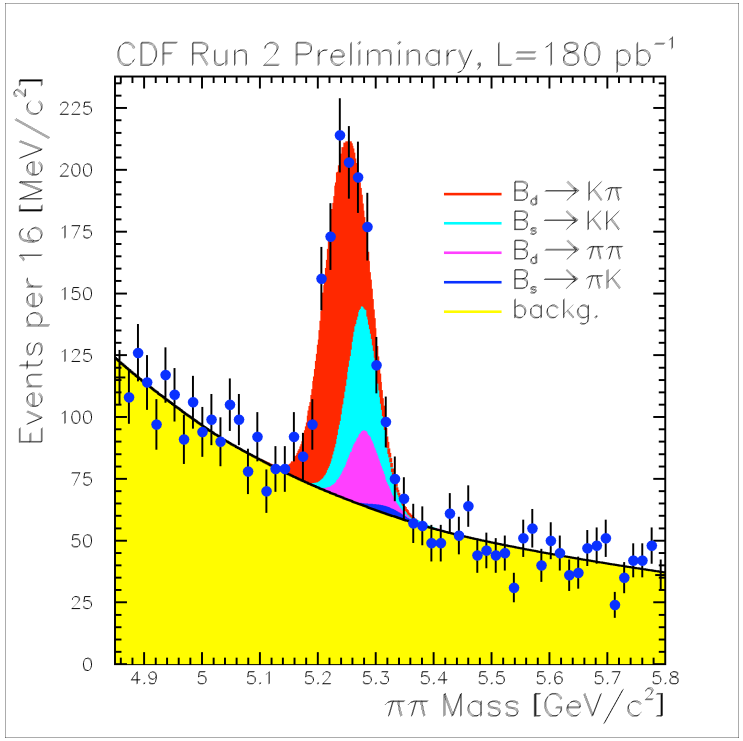
$$BR(B_s \to \phi\phi) = (1.4 \pm 0.6 \pm 0.2 \pm 0.5) \times 10^{-5}$$

Charmless $B_{d,s} \to h^+h^{-\prime}$ (π,K):

See Giovanni Punzi talk

- ✓ Measured relative B_s/B_d Branching Ratios
- Determine $\Delta\Gamma(B_s \to KK)$ and compare to $\Delta\Gamma(B_s \to J/\psi\phi)$
- Measure direct $\not{CP}$: $B_d \to K^+\pi^-$ eventually also $B_s \to K^-\pi^+$
- Extract γ, eventually

Branching Ratios and CP Asymmetries: $B \to h'h$



Decay	# B
$B_d \to K^+\pi^-$	509
$B_d \to \pi^+\pi^-$	134
$B_s \to K^+K^-$	232
$B_s \to K^-\pi^+$	---

Agrees with B-factories

$$\frac{BR(B_d \to \pi^\pm\pi^\mp)}{BR(B_d \to K^\pm\pi^\mp)} = 0.24 \pm 0.06(stat) \pm 0.05(syst)$$

$$\frac{f_s}{f_d}\frac{BR(B_s \to K^\pm K^\mp)}{BR(B_d \to K^\pm\pi^\mp)} = 0.50 \pm 0.08(stat) \pm 0.07(syst)$$

$$\frac{BR(B_s \to \pi^\pm\pi^\mp)}{BR(B_s \to K^\pm K^\mp)} < 0.10 @ 90\% C.L.$$

$$\frac{f_s}{f_d}\frac{BR(B_s \to K^\pm\pi^\mp)}{BR(B_d \to K^\pm\pi^\mp)} < 0.11 @ 90\% C.L.$$

$$A_{CP} = \frac{N(B_d \to K^-\pi^+) - N(B_d \to K^+\pi^-)}{N(B_d \to K^-\pi^+) + N(B_d \to K^+\pi^-)} = -0.04 \pm 0.08(stat) \pm 0.01(syst)$$

Babar: A_{CP} =-0.133±0.030(stat.)±0.009(syst.) Belle: A_{CP} =-0.101±0.025(stat.)±0.005(syst.)

B. R. and CP Asymmetries in D Decays

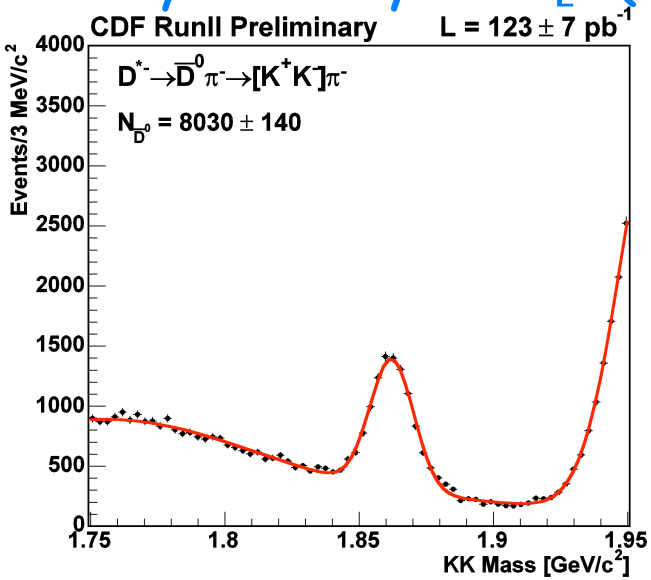
$\Gamma(D^0 \to KK)/\Gamma(D^0 \to K\pi) = (9.92 \pm 0.11(\text{stat.}) \pm 0.12(\text{syst.}))\%$

better than PDG $(10.23 \pm 0.21)\%$

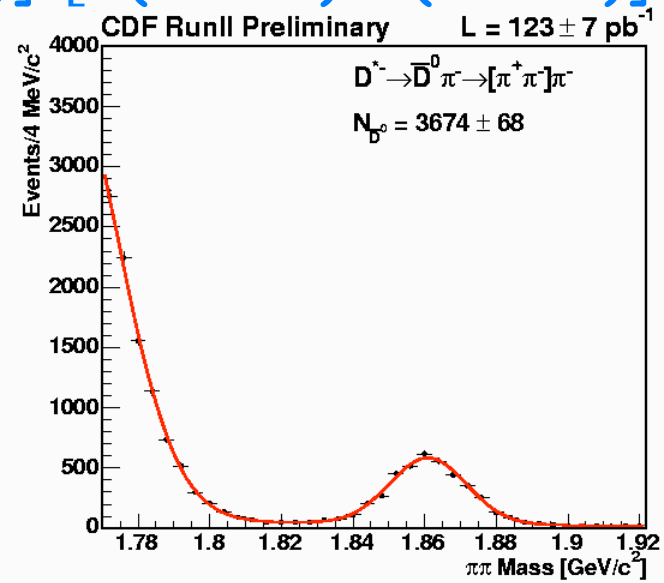
$\Gamma(D^0 \to \pi\pi)/\Gamma(D^0 \to K\pi) = (3.594 \pm 0.054(\text{stat.}) \pm 0.040(\text{syst.}))\%$

better than PDG $(3.62 \pm 0.10)\%$

CP Asymmetry: $A = [\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to f)]/[\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to f)]$



Tag D^0 flavor using π charge from D*



$A(D^0 \to KK) = (2.0 \pm 1.2 \pm 0.6)\%$

better than PDG $(0.5 \pm 1.6)\%$

$A(D^0 \to \pi\pi) = (1.0 \pm 1.3 \pm 0.6)\%$

better than PDG $(2.1 \pm 2.6)\%$

More Charm in Alessandro Cerri talk

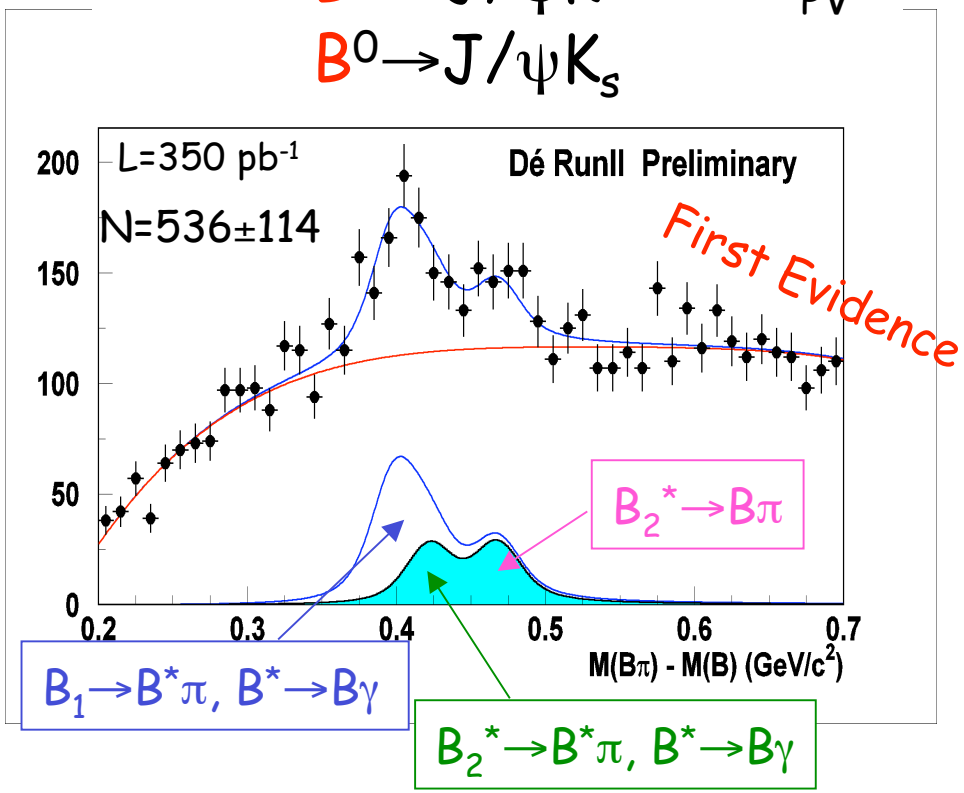
Resonant structures in $B\pi^{\pm}$ system at D0

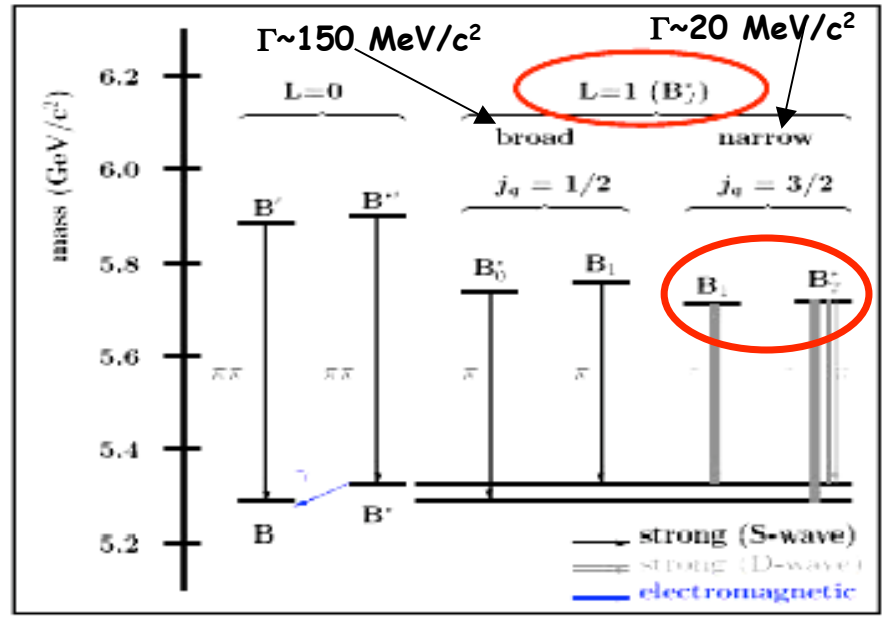
Orbitally excited states L=1, B^{**}

$\Delta m_{J1/2,\,J3/2}$~100 MeV/c^2

In this analysis

B^{**} = $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$ + π_{PV}, $B^0 \to J/\psi K_s$



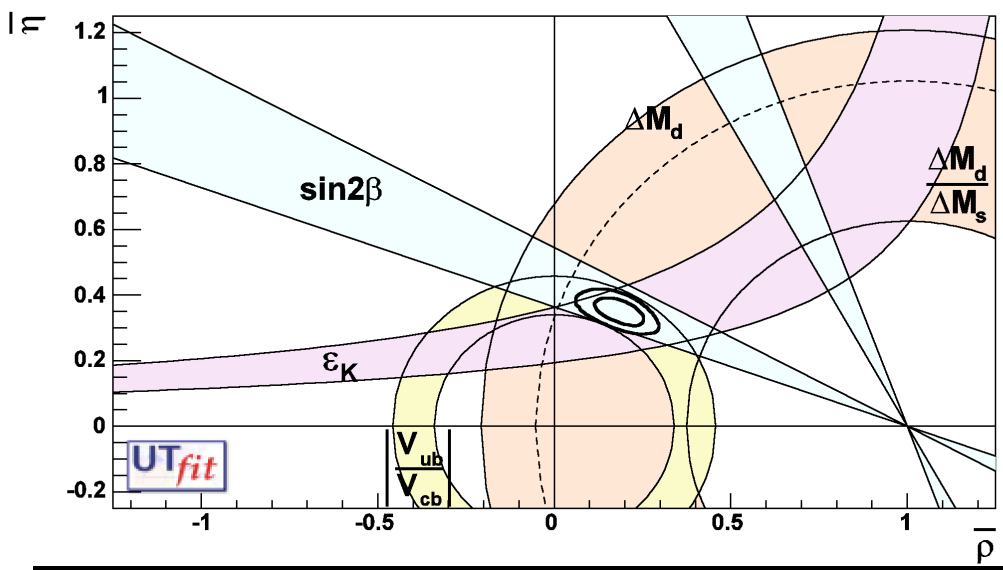


$M(B_1)$=5724±4(stat.)±7(syst.) MeV/c^2

$M(B_2^*)-M(B_1)$=
23.6±7.7(stat.)±3.9(syst.) MeV/c^2

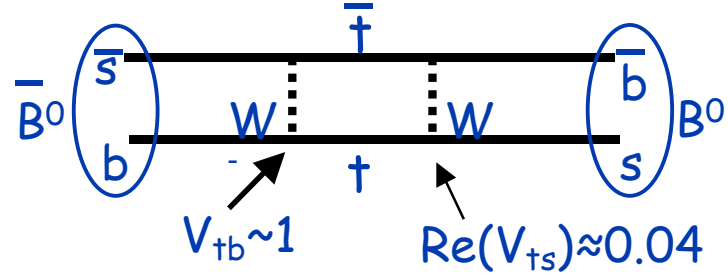
$\Gamma_1=\Gamma_2$ =
23±12(stat.)±9(syst.) MeV/c^2

Mixing and CKM Triangle



Parameter	Value ± Error	99% Probability
$\bar{\eta}$	0.348±0.028	[0.275-0.418]
$\bar{\rho}$	0.172±0.047	[0.051-0.302]
sin(2β)	0.725±0.033	[0.627-0.793]
sin(2α)	-0.16±0.26	[-075-0.48]
γ^o	61.5±7.0	[42.3-81.6]
$\Delta m_s(ps^{-1})$	18.3±1.6	[15.1-27.0]

Δm_d=0.502±0.007 ps^{-1}



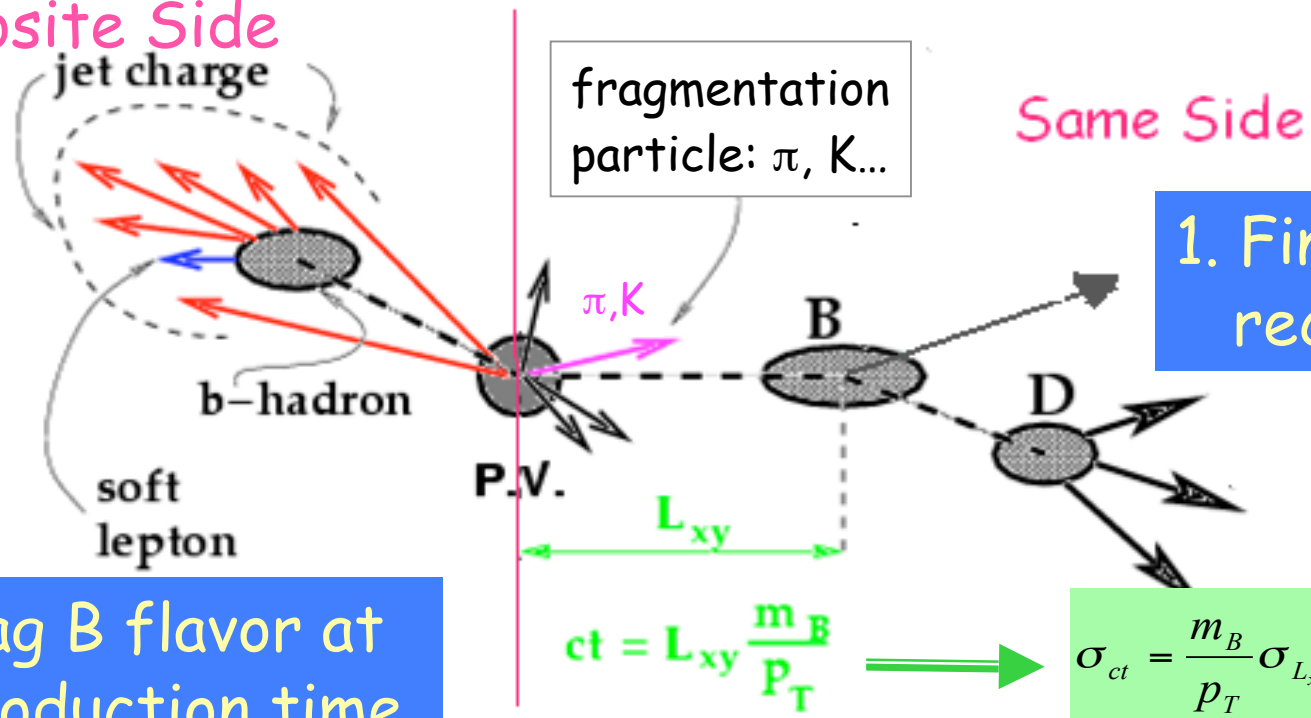
Re(V_{ts})≈0.04 > Re(V_{td})≈0.007

$\Delta m_s >> \Delta m_d$

World Average limit
Δm_s > 14.4 ps^{-1}

B mixing: what we need

Opposite Side



1. Final state reconstruction

$$\sigma_{ct} = \frac{m_B}{p_T}\sigma_{L_{xy}} \oplus ct\left(\frac{\sigma_{p_T}}{p_T}\right)$$

2. High resolution on proper decay length

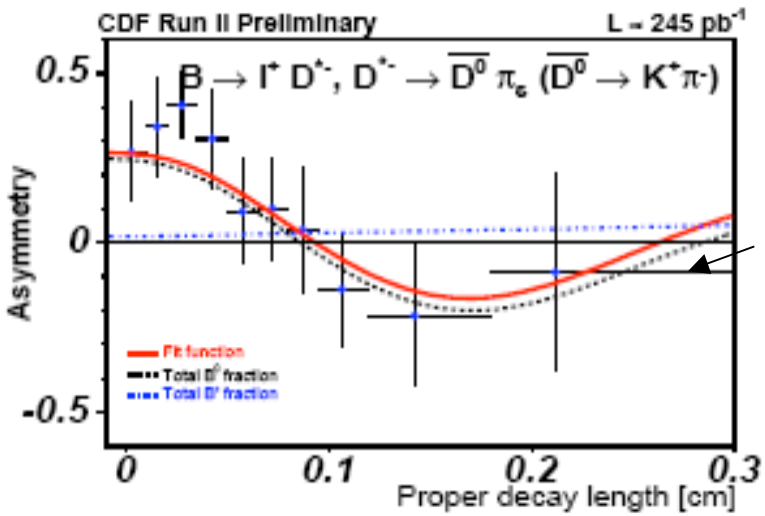
3. Tag B flavor at production time

measure efficiency ε and dilution D: εD^2 gives the "effective" number of events

B_d mixing Results

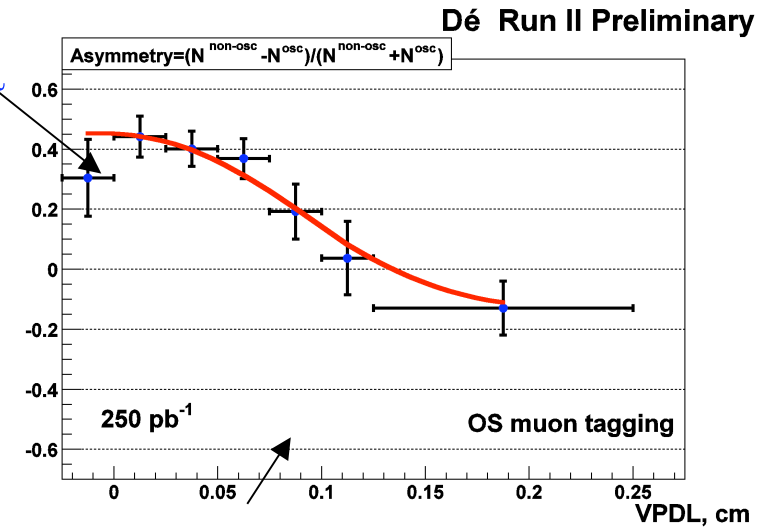
Philip Gutierrez talk for details

B_d mixing measurements ⇒ test the machinery for B_s



Opposite Side taggers

Soft μ tagger



$\Delta m = 0.506 \pm 0.055(stat) \pm 0.049(sys)\ ps^{-1}$

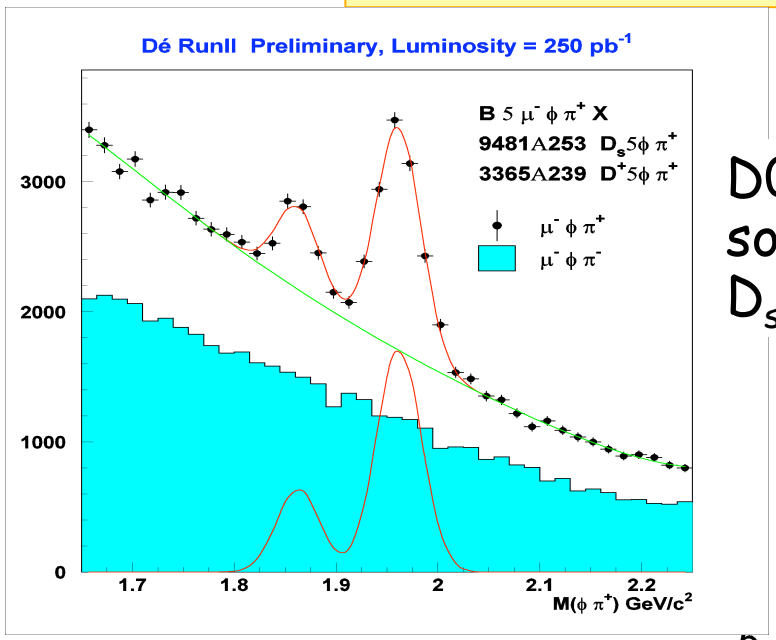
Combined tagger:

$\Delta m = 0.536 \pm 0.037(stat) \pm 0.009(s.c) \pm 0.015(sys)\ ps^{-1}$

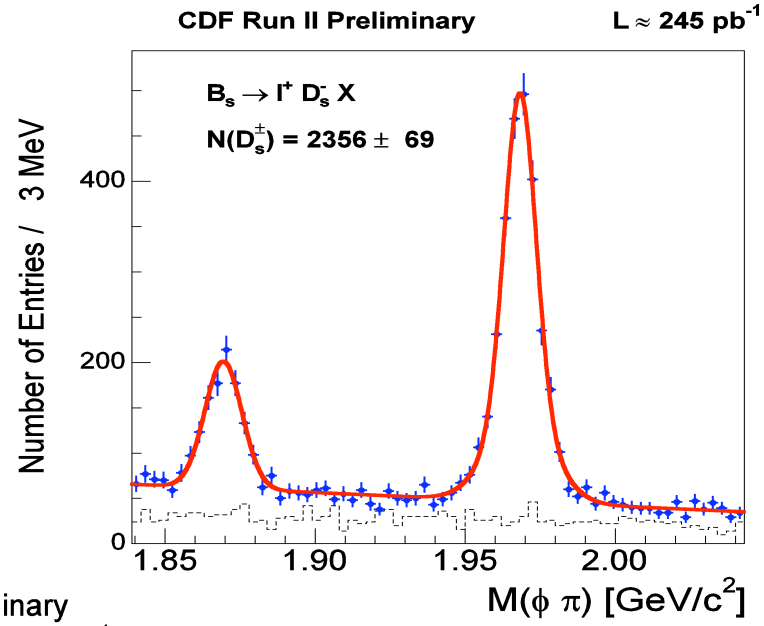
$\varepsilon D^2 = 1.820 \pm 0.114\ (\%)$

εD^2(%)	CDF	D0
SST	1.04±0.35±0.06	1.00±0.36
Soft μ	$0.698 \pm 0.042\ ^{+0.051}_{-0.027}$	1.00±0.38
Soft e	0.35±0.05(stat)	-
Jet-Q	0.715±0.027	~1

B_s Mixing Sensitivity: Limit



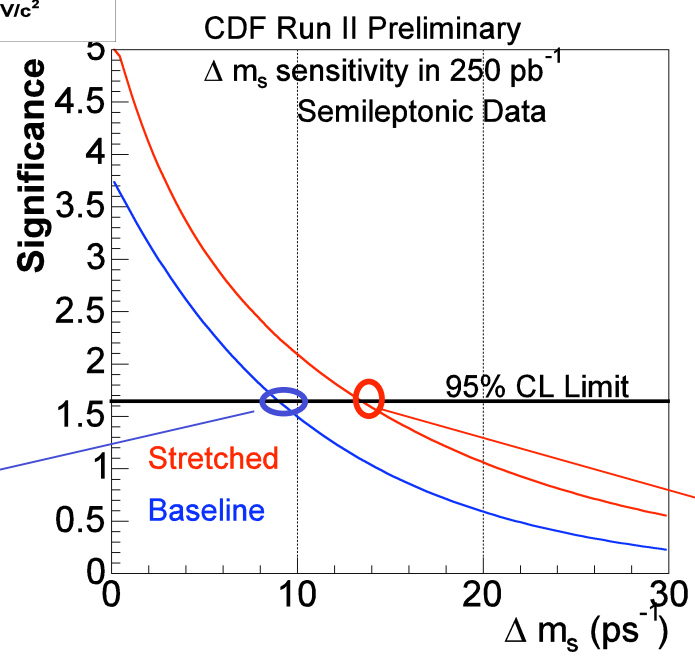
D0 will have soon $D_s \rightarrow K^*K$



D0 Yield:≈37/pb^{-1}

CDF Yield:≈10/pb^{-1}

CDF Baseline:
$\varepsilon D^2 = 1.6\%$
$\sigma_t = 67$ fs

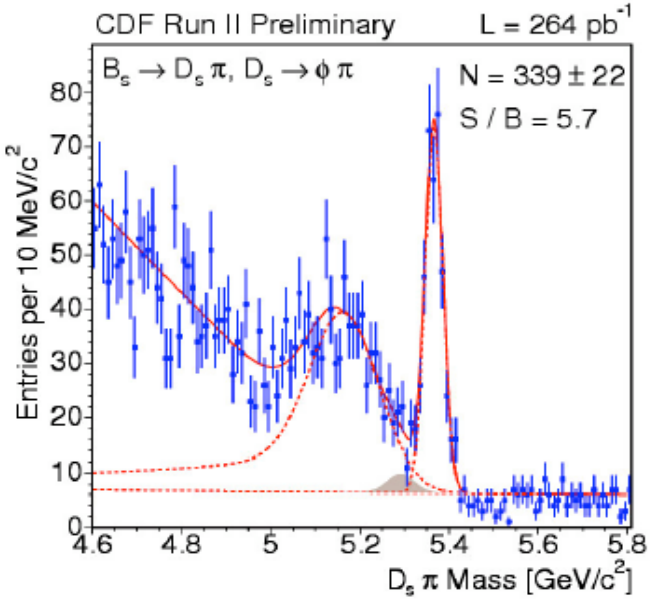


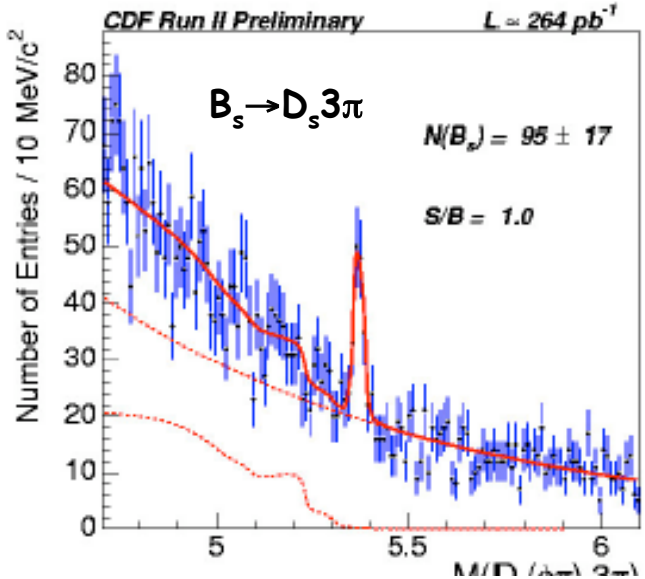
CDF Stretched:
$\varepsilon D^2 = 2.6\%$
$\sigma_t = 47$ fs

$\Delta m_s \sim 9$ ps^{-1}

$\Delta m_s \sim 15$ ps^{-1}

B_s Mixing sensitivity: Limit (Combined Datasets)





Semileptonic and hadronic decays:

$B_s \to D_s \pi$ and $B_s \to D_s 3\pi$

$D_s \to \phi\pi$ $\quad$ $D_s \to \phi\pi$

$D_s \to 3\pi$

$D_s \to K^*K$

CDF Baseline:

$\varepsilon D^2 = 1.6\%$

$\sigma_t = 67$ fs

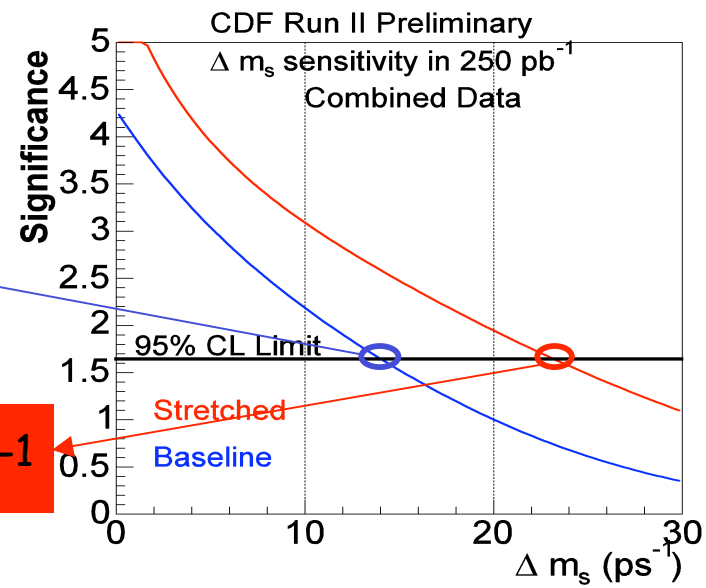
$\Delta m_s \sim 14$ ps^{-1}

CDF Stretched:

$\varepsilon D^2 = 2.6\%$

$\sigma_t = 47$ fs

$\Delta m_s \sim 23$ ps^{-1}



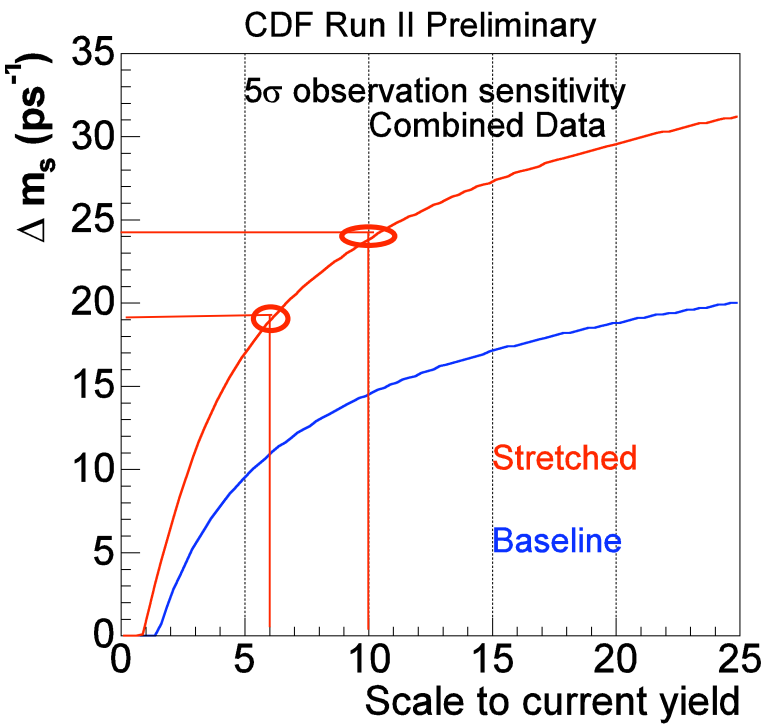
B_s Mixing sensitivity: CDF Reaches

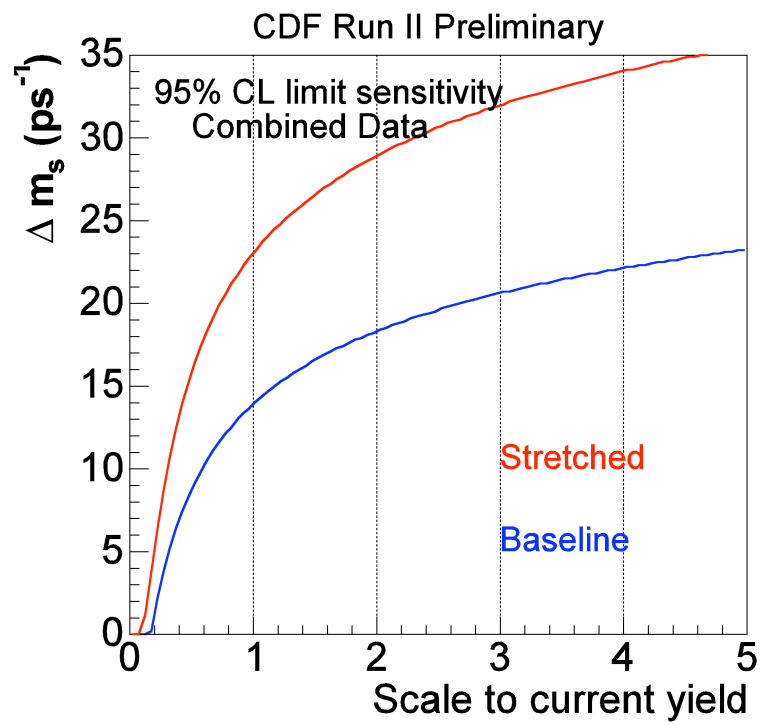
5σ observation:

CDF Stretched:
$\varepsilon D^2 = 2.6\%$
$\sigma_t = 47$ fs

$\Delta m_s = 19\ ps^{-1}$ ~6 times more data

$\Delta m_s = 24\ ps^{-1}$ ~10 times more data





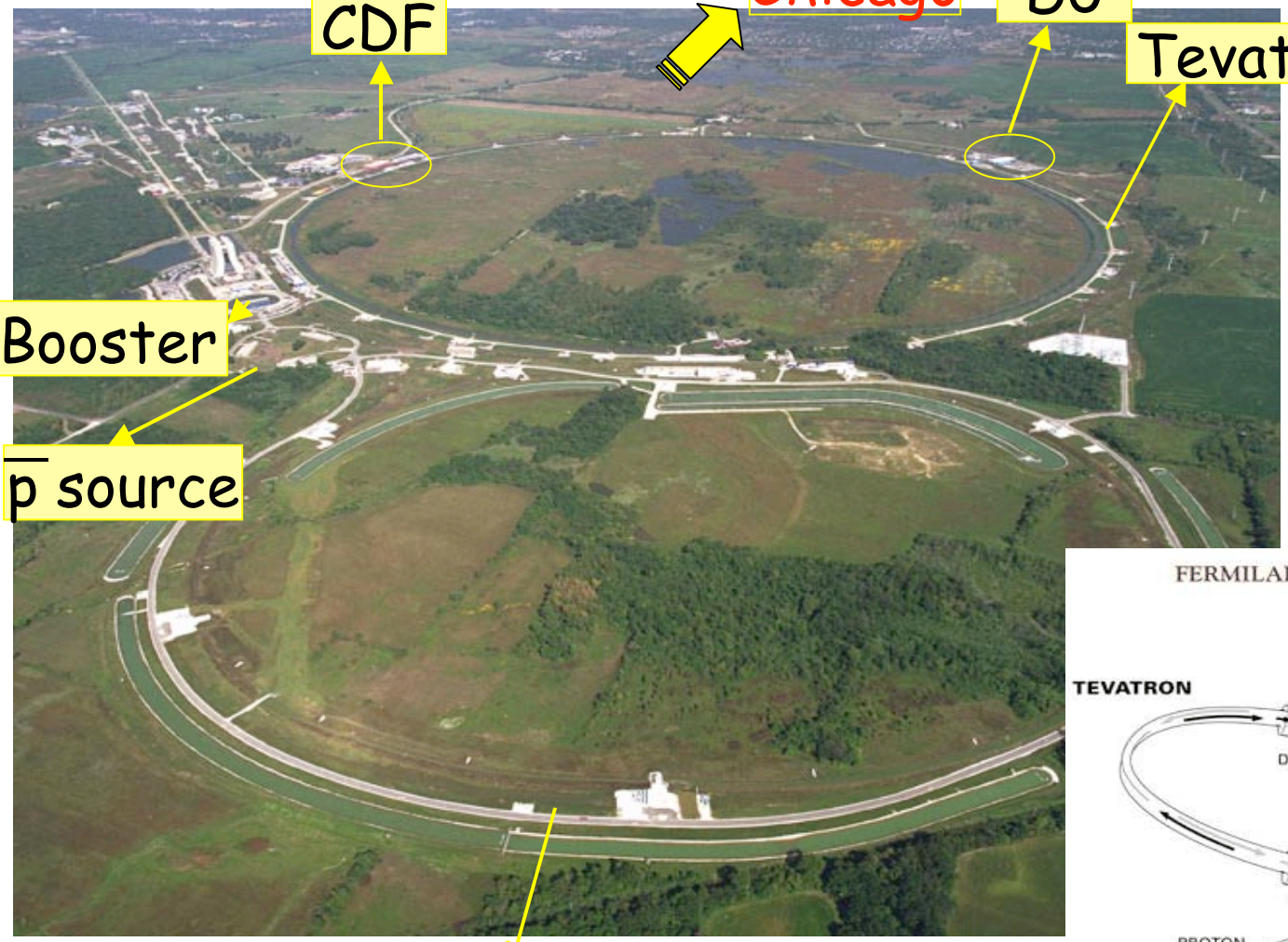
Summary & Conclusions

- Rich program at the Tevatron !
- QCD
  - different jet algorithms
  - constrain gluon PDFs at high x
  - study boson +jet physics
  - measure B +jet cross section…
- Beauty and Charm competitive with dedicated experiments:
  - ~~CP~~ being investigated in B and D decays
  - Lifetimes measured for B^0, $B^{\pm}$, B_s and Λ_b
  - All the machinery for B_s mixing measurement ready…

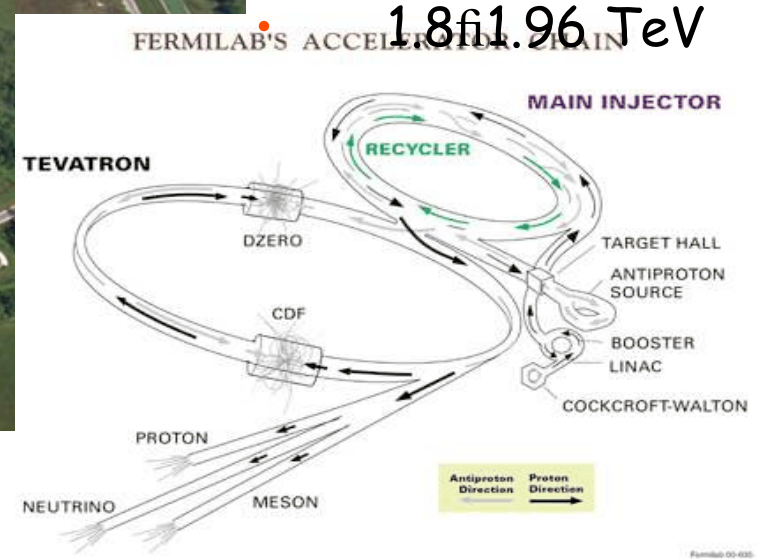
… keep an eye on the Tevatron: something could be around the corner.

Backup slides

The Machine

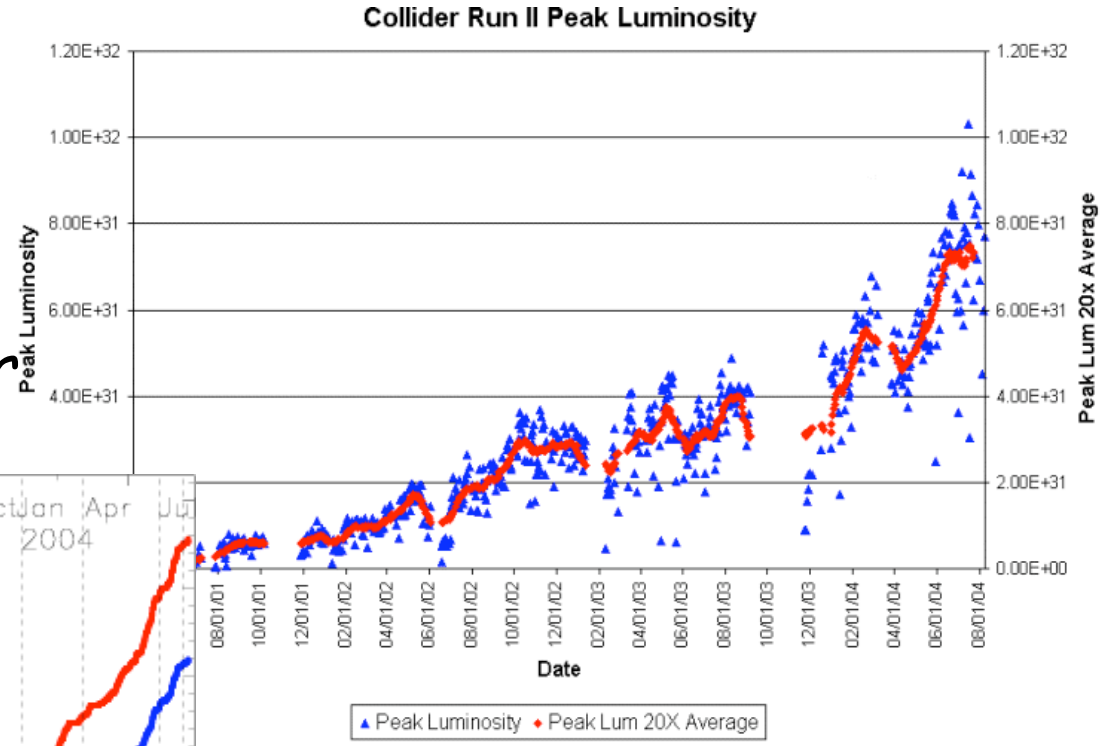


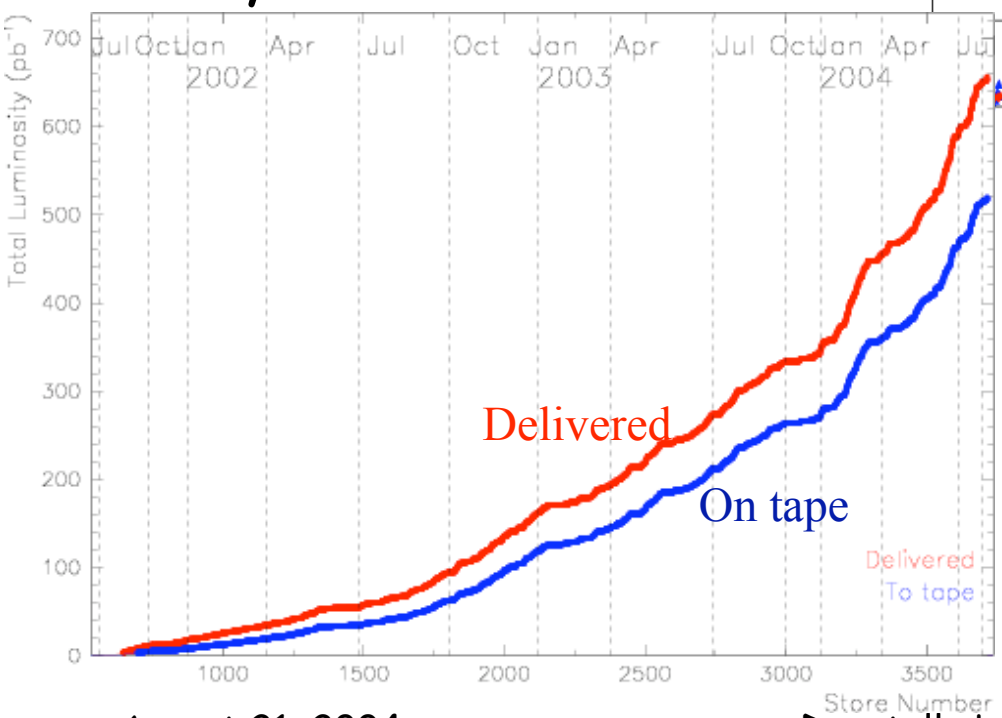
- L^{goal}_{peak}: $\sim 2\times10^{32} s^{-1} cm^{-2}$
- 36 bunches
- 396 ns crossing time
- $\sqrt{s}$ = 1.8 fi 1.96 TeV



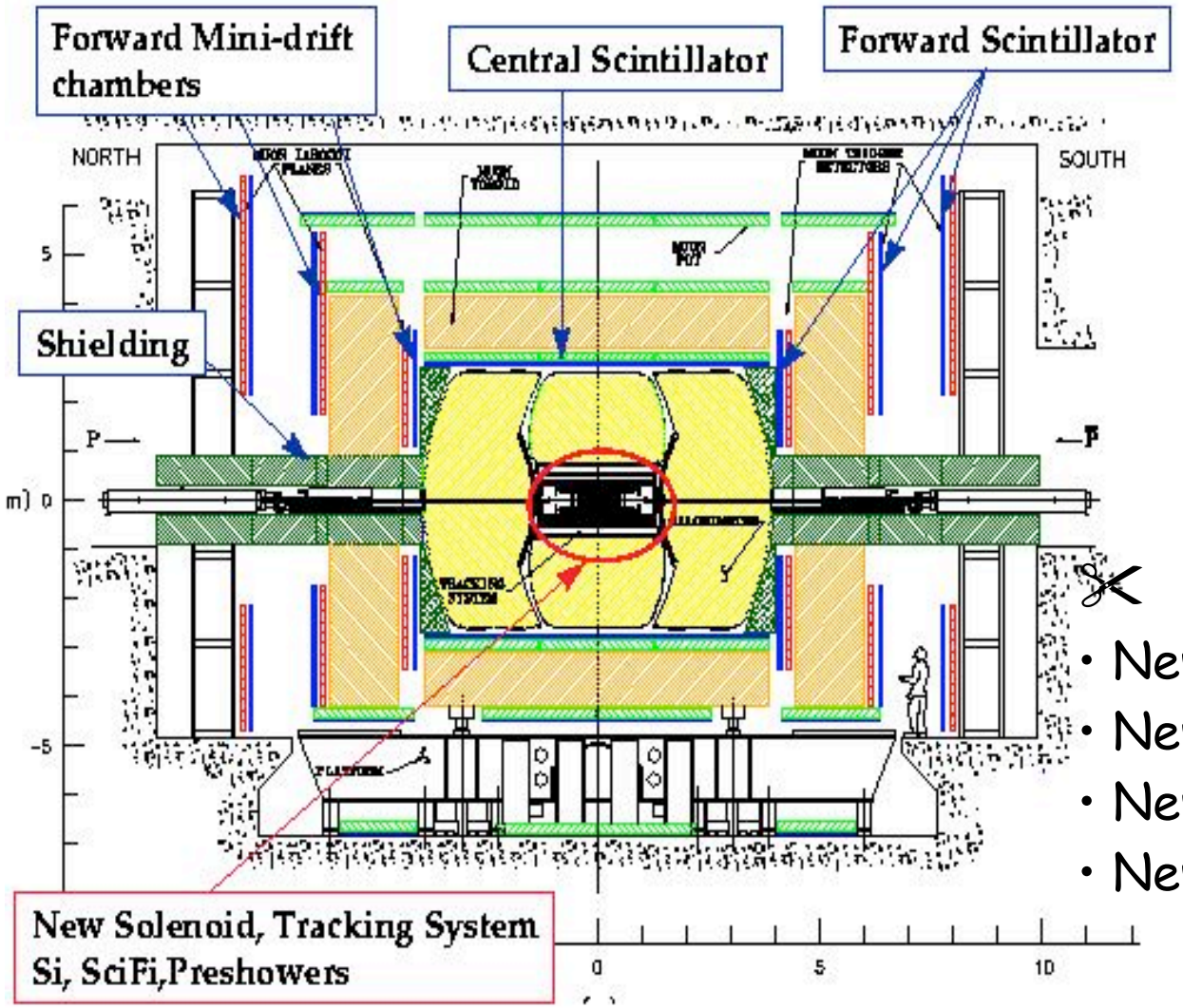
TeVatron Luminosity

- Peak luminosity
  - Best 1.01×10^{32}
- Delivered/on tape
  - 660/520 pb^{-1}
- ~ 450 pb^{-1} available for analysis now



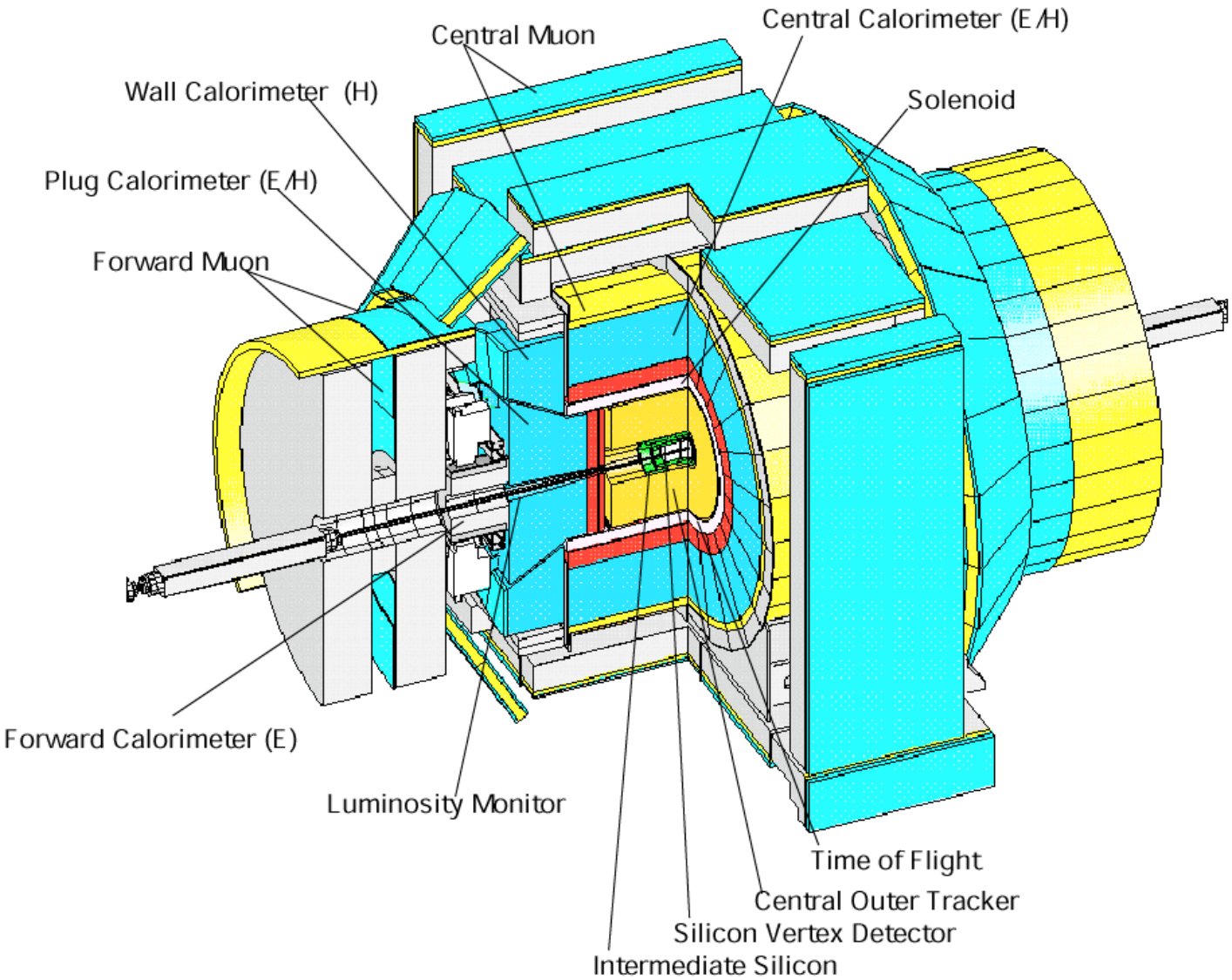


The D0 Detector

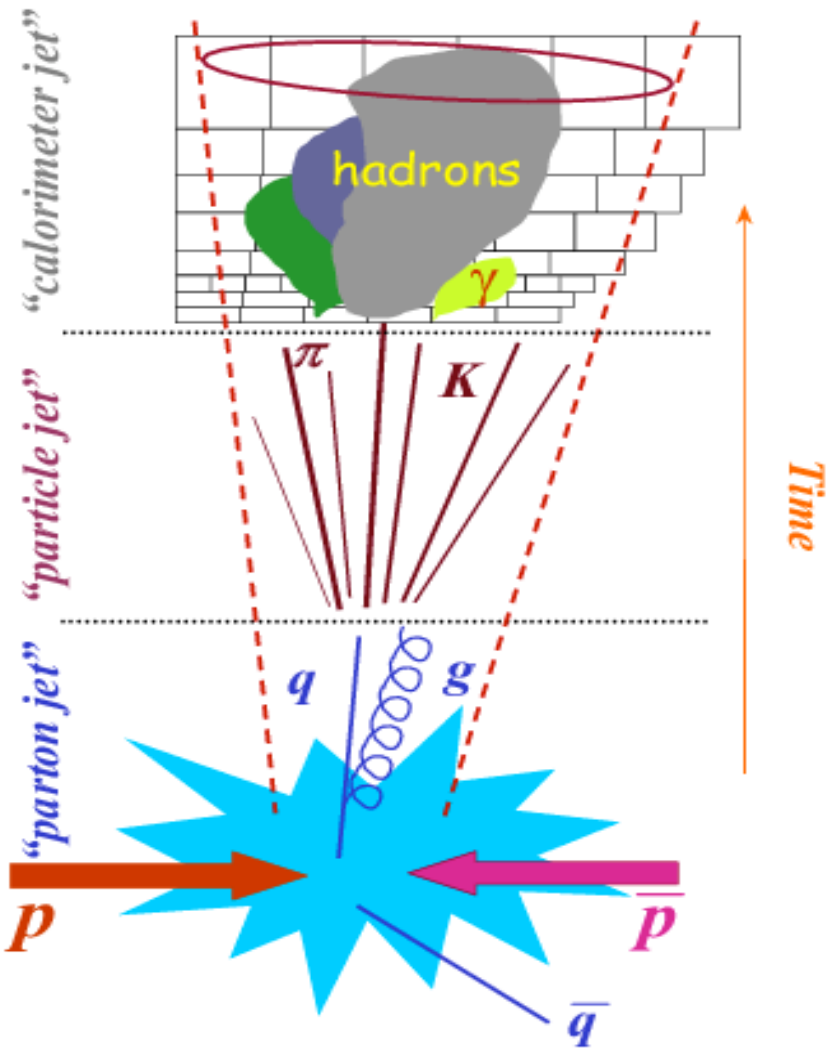


- Upgraded muon coverag
- New Tracking System
- New Silicon Micro-vertex
- New Solenoid
- New Pre-showers

The CDF Detector



Jet Physics at 2 TeV : Jet algorithm



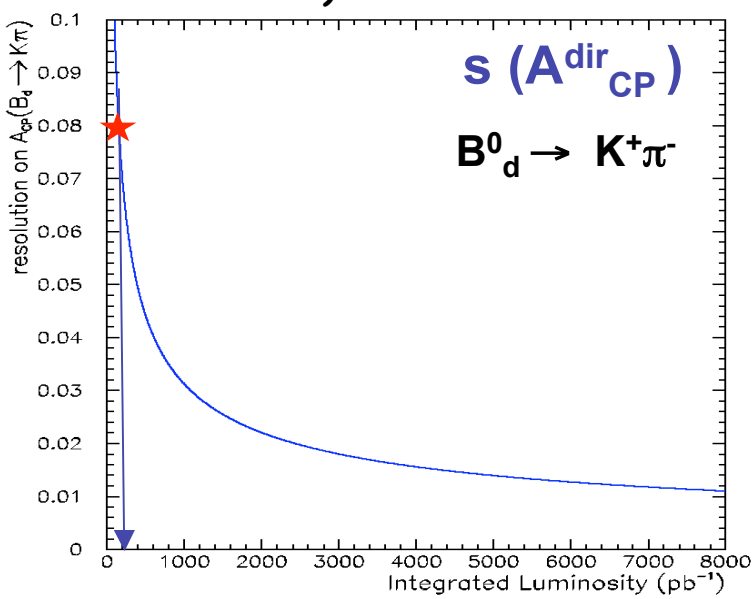
- Measurements performed at hadron level.
- Theory: known at parton level
- Hadron Æ parton transition depends on parton shower modeling
- Jet algorithm definition is fundamental to compare data and theory
- Use of cone based algorithm in h-f space

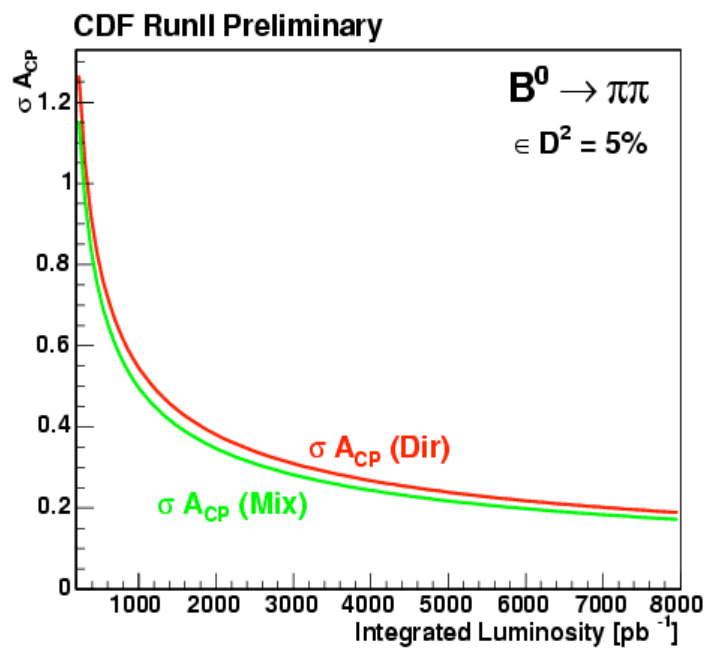
Prospect for B→h'h

Systematic uncertainty at the same level

- σ(CDF) ~ σ(Babar)/0.7 for same size samples
- CDF currently has ~3 times more events on tape:
  - same yields as current 200fb^{-1} Babar
  - Expect ACP measurement at ~4.5% level from available data

(does not account for latest improved tracking and inclusion of TOF in PID)





B_s Mixing sensitivity: semileptonic decays

CDF Baseline:

$\varepsilon D^2 = 1.6\%$

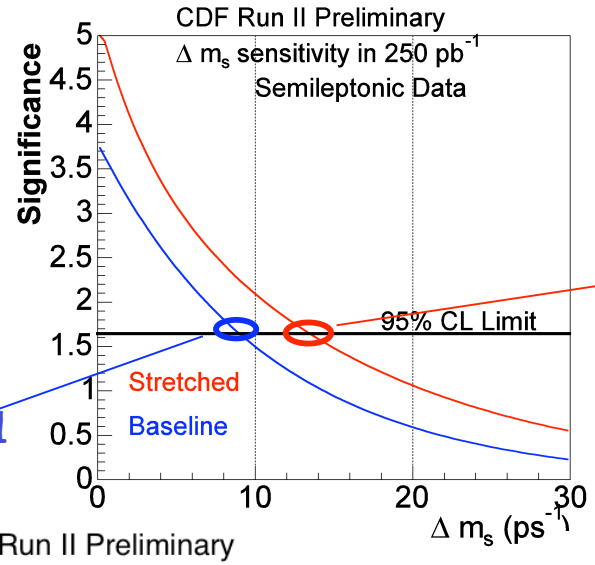
$\sigma_t = 67$ fs

CDF Stretched:

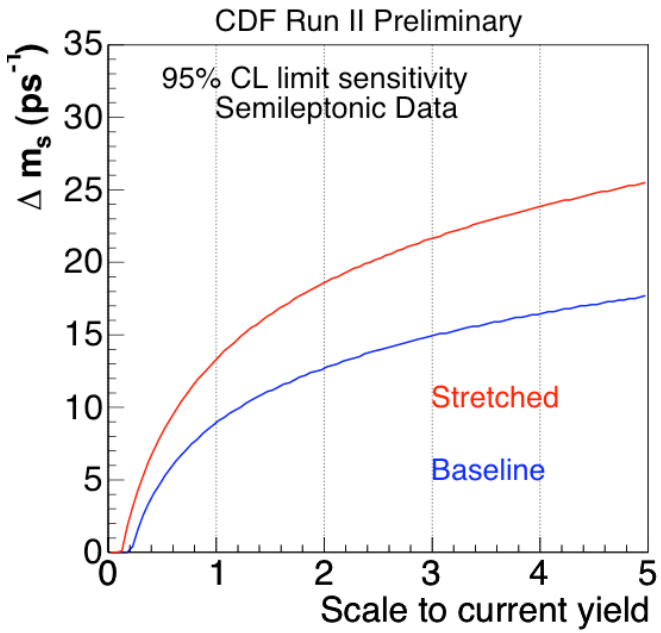
$\varepsilon D^2 = 2.6\%$

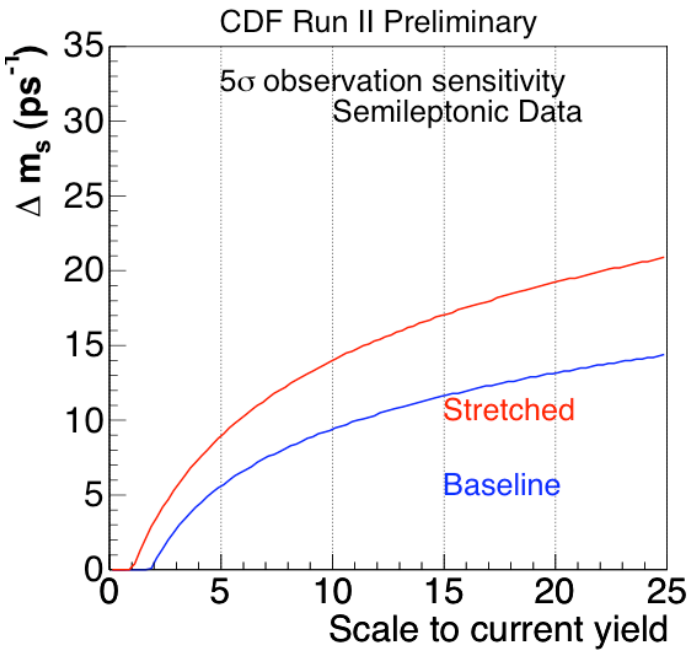
$\sigma_t = 47$ fs

$\Delta m_s \sim 9 ps^{-1}$



$\Delta m_s \sim 15 ps^{-1}$





B_s Mixing sensitivity: hadronic decays

Yields per 250 pb^{-1}

$B_s \to D_s\pi$ and $B_s \to D_s 3\pi$

$D_s \to \phi\pi$ 320 $D_s \to \phi\pi$ 90

$D_s \to 3\pi$ 115

$D_s \to K^*K$ 200

CDF Baseline:

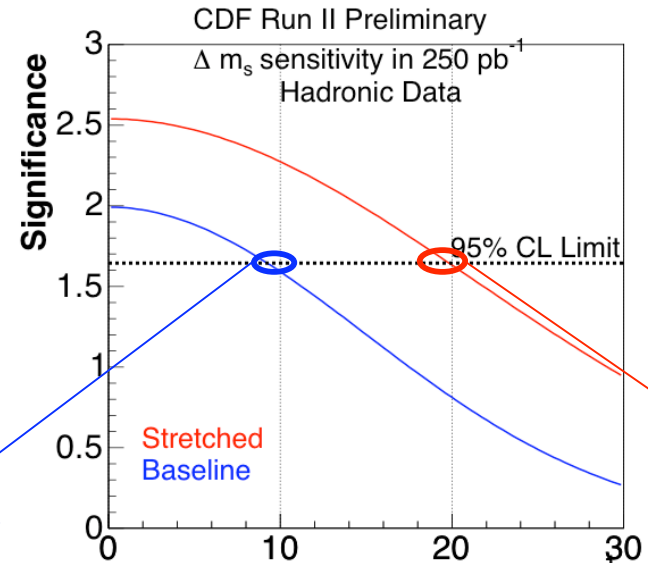
$\varepsilon D^2 = 1.6\%$

$\sigma_t = 67$ fs

CDF Stretched:

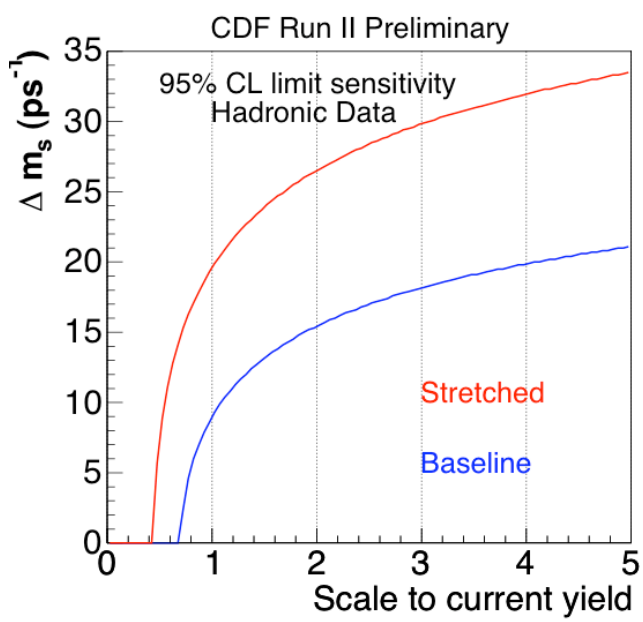
$\varepsilon D^2 = 2.6\%$

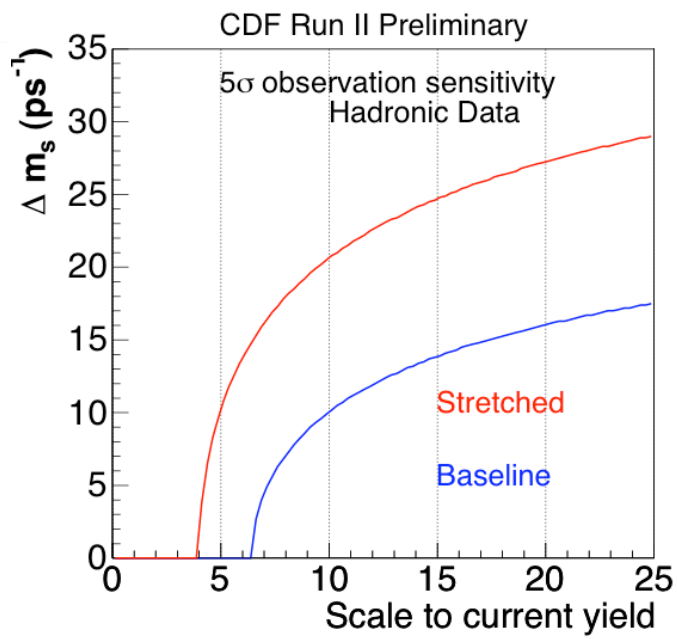
$\sigma_t = 47$ fs



$\Delta m_s \sim 9 ps^{-1}$

$\Delta m_s \sim 20\ ps^{-1}$





Rare Decays: $B_{d,s} \to \mu\mu$

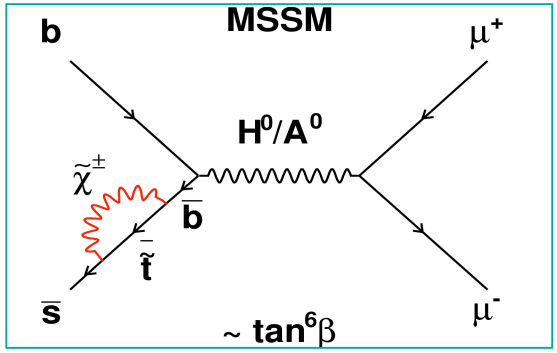
See Matt Herndon talk

Only via Flavor Changing Neutral Current in SM

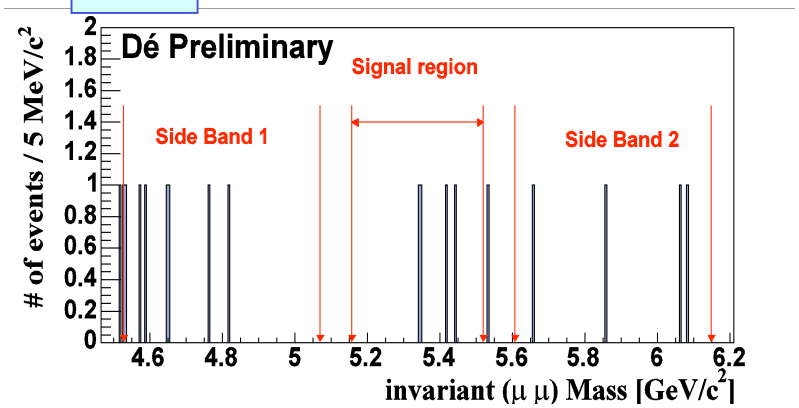
$BR_{SM}(B_s \to \mu^+\mu^-) = (3.4 \pm 0.5) \times 10^{-9}$

$BR_{SM}(B_d \to \mu^+\mu^-) = (1.00 \pm 0.14) \times 10^{-10}$

Large enhancements predicted in other Models: MSSM, mSUGRA, SO(10) ,RVP

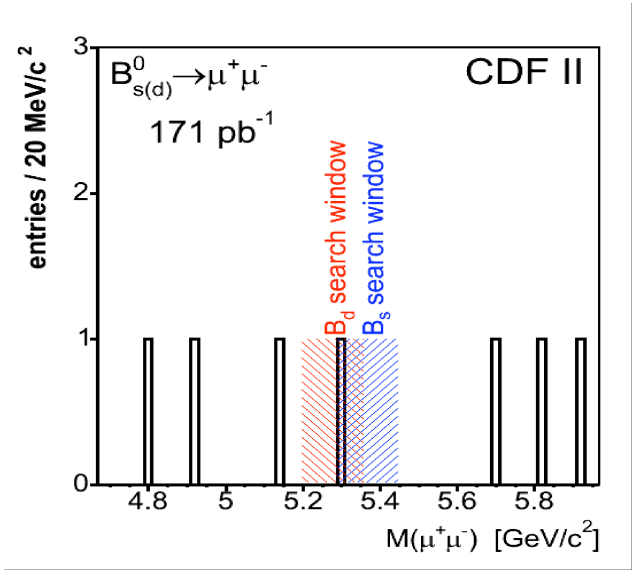


DO



$BR(B_s \to \mu\mu) < 3.8 \cdot 10^{-7}$ @90% C.L.

CDF



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

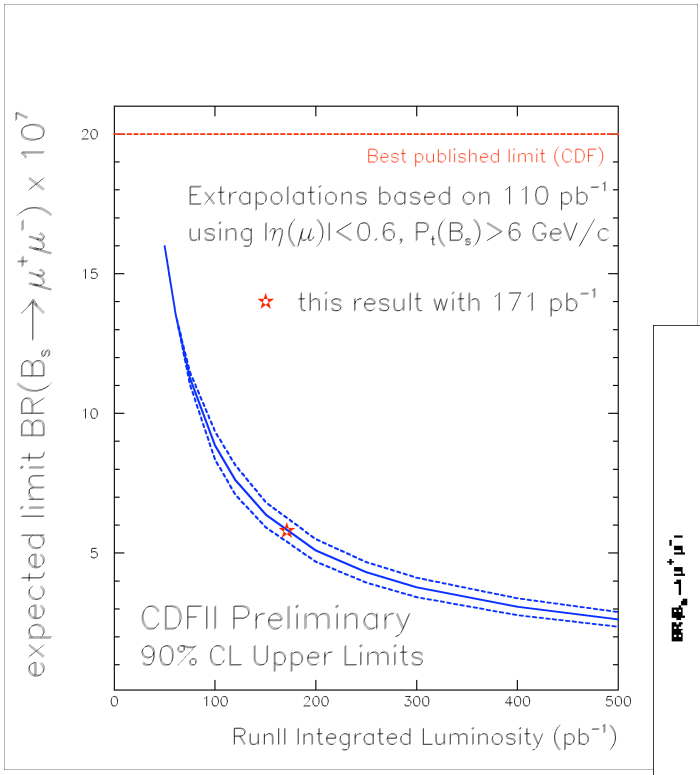
$BR(B_d \to \mu\mu) < 1.5 \cdot 10^{-7}$

$B_{d,s} \to \mu\mu$: Future

Combined $BR(B_s \to \mu\mu) < 2.7 \times 10^{-7}$ @90% C.L.

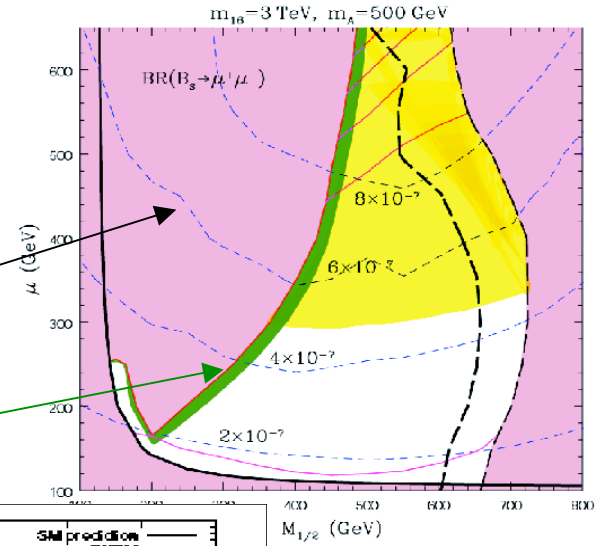
New limits exclude large regions of previously allowed parameters

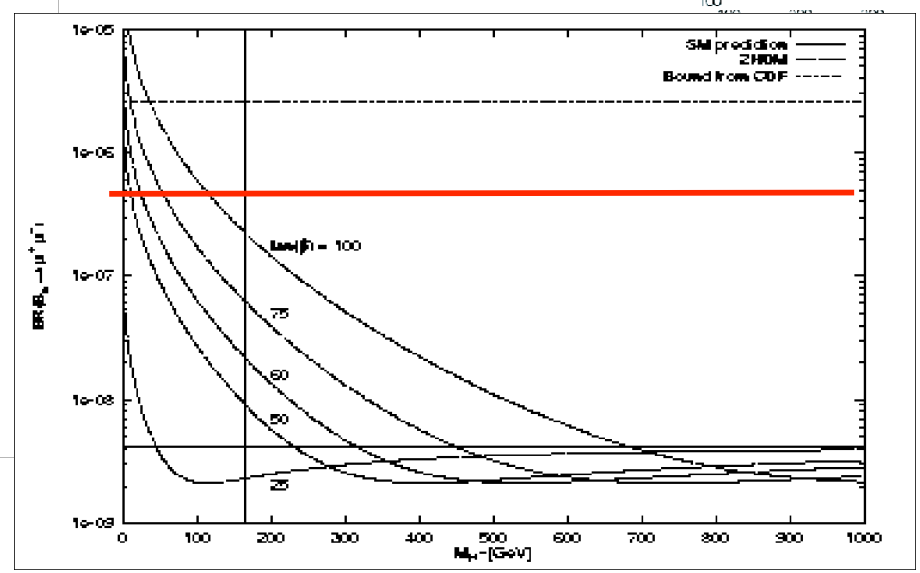
SO(10)



Contours of constant $BR(B_s \to \mu\mu)$

Allowed by Dark Matter constraints





MSSM