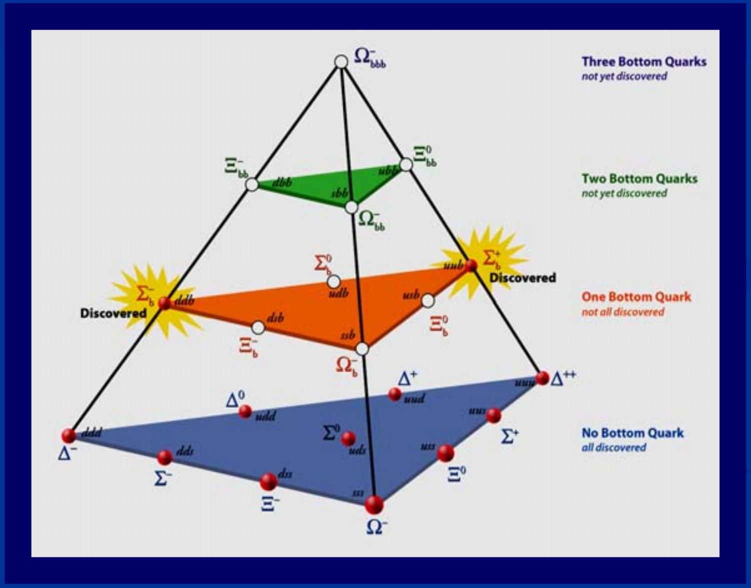
Recent b-physics results from CDF



Elena Vataga (Univ. of New Mexico)
On behalf of the CDF Collaboration

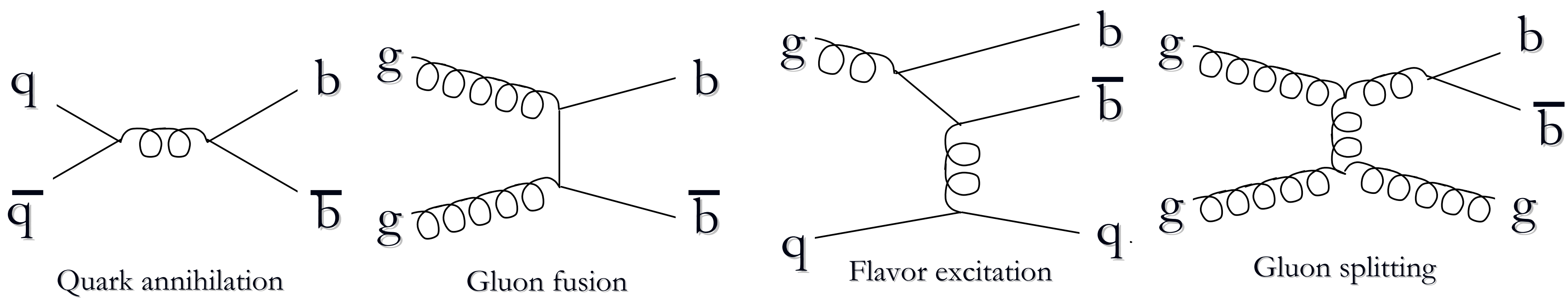
PHENO 07 – May 7th 2007

Outline

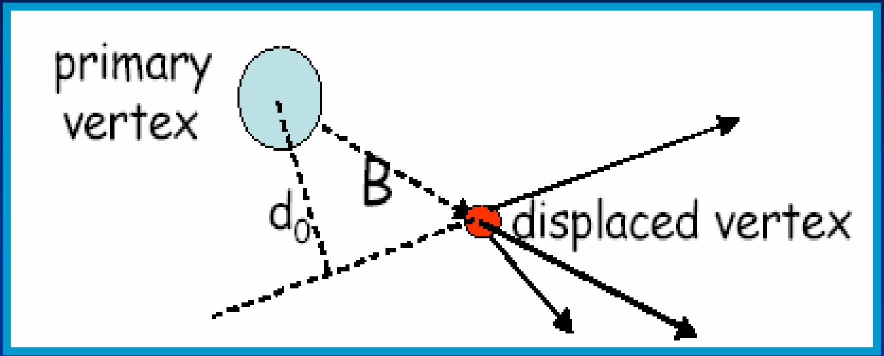
- Introduction:
  - Experimental challenges
- Recent Results covered here
  - Rare B decays ($B_{s,d} \to \mu\mu$, $B_s \to \mu\mu\phi$)
  - Measurement of B_s oscillation frequency
  - Λ_b lifetime measurements
  - B Spectroscopy
- Summary

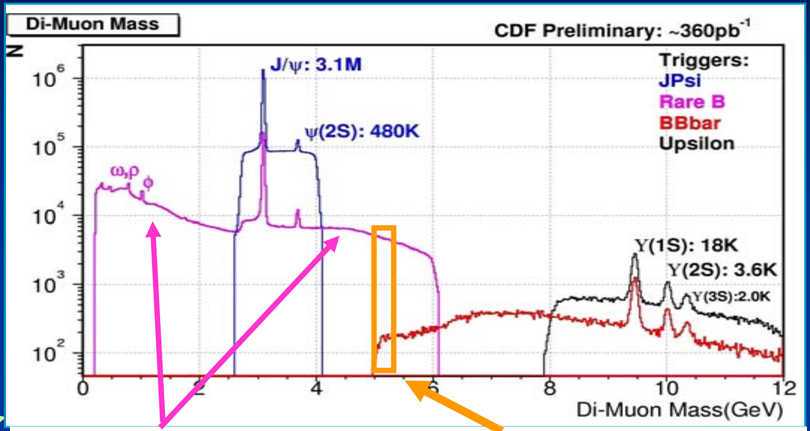
B physics @ Tevatron

- **Pro:**
  - Enormous cross-section: ~50 μb, reconstructable: 3÷5 μb
  - All species of b-hadrons: B_u B_d B_s B_c Λ_b Σ_b
- **Contro:**
  - QCD background ×10^3 larger than σ(*bb*)
  - Collision rate ~1MHz → tape writing limit ~100 Hz
  - Soft p_T(B) spectrum (~10 GeV/c)



B physics @ CDF: triggers are crucial



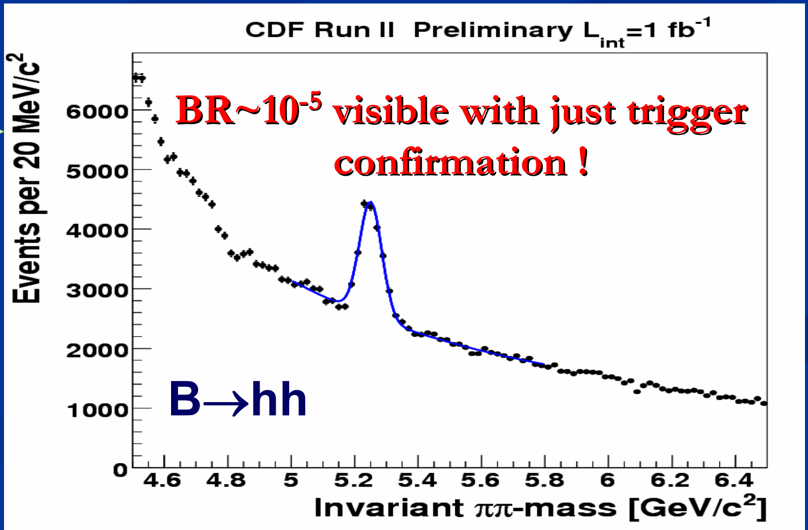


B→μμh search region

B→μμ search region

Trigger configurations:

1. Di-muon
2. Lepton plus displaced track
3. 2 displaced tracks

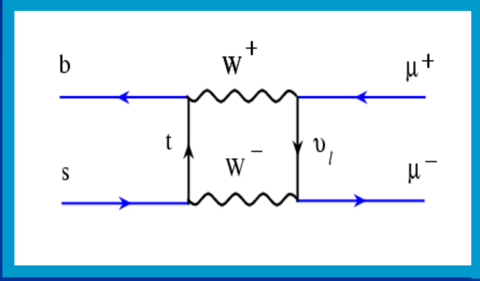


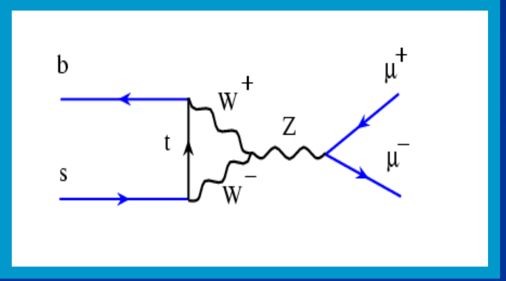
Secondary Vertex Trigger (SVT) is unique to CDF!

First of its kind to trigger on fully hadronic *b/c* decays

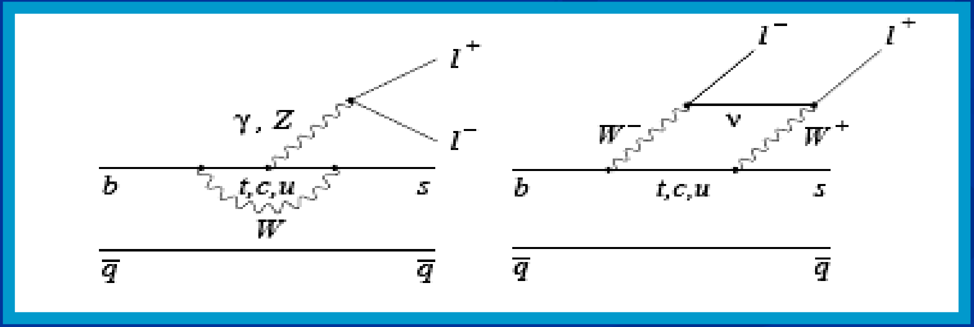
Rare B decays
indirect search for new Physics

- $B \to \mu\mu$



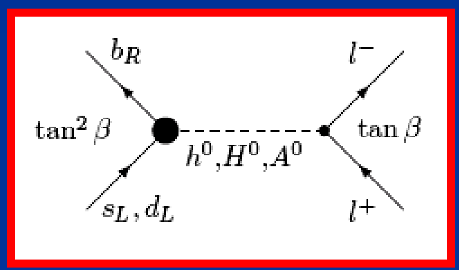


- $B \to \mu\mu h$

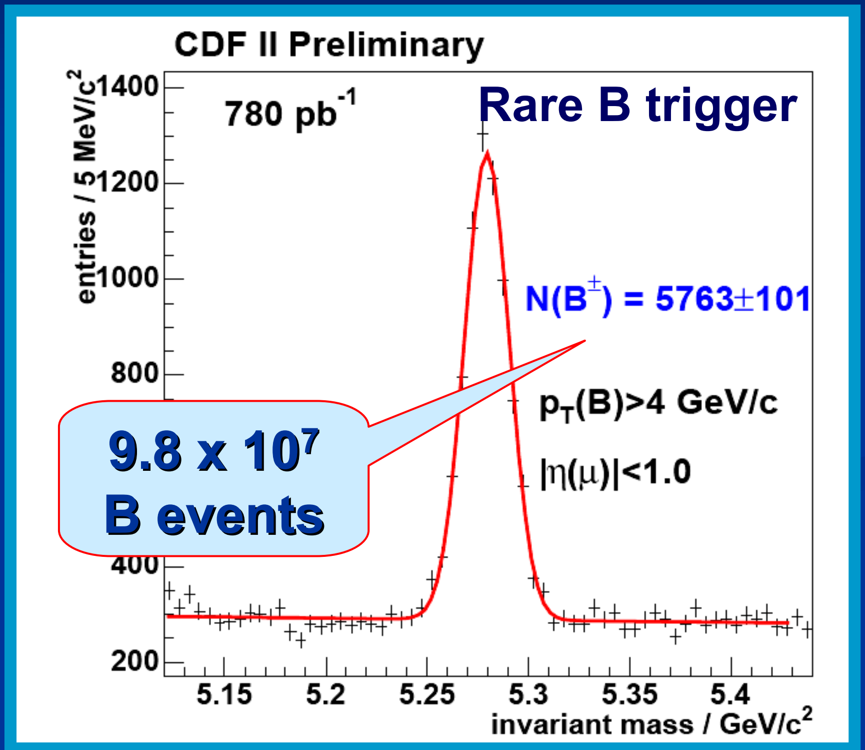


$B_{s(d)} \to \mu\mu$

- **Motivation:**
  - **SM** Br($B_s \to \mu\mu$) ~ 3.5 x 10^{-9}
  - Sizeable **New Physics Enhancement** predicted in many scenario



- **Method:**
  - Measure the rate of $B_{s(d)} \to \mu\mu$ decays relative to $B \to J/\psi K$ mode
  - Apply the same trigger/selection criteria $\Rightarrow$ reduce systematic

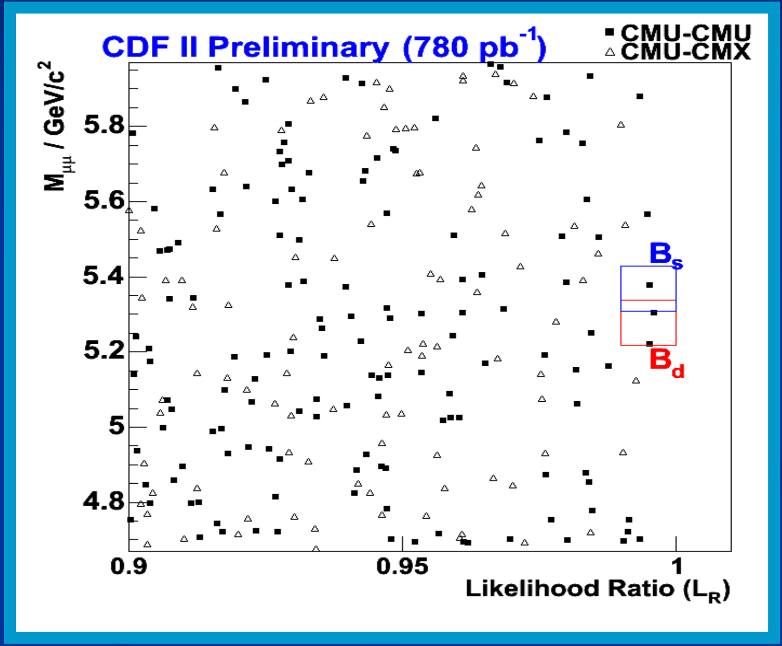


$$BR(B_s \to \mu^+\mu^-) = \frac{N_{Bs}}{N_{B+}} \frac{\alpha_{B+} \cdot \varepsilon_{B+}^{total}}{\alpha_{Bs} \cdot \varepsilon_{Bs}^{total}} \frac{f_{b\to B+}}{f_{b\to Bs}} BR(B^+ \to J/\psi K^+) BR(J/\psi \to \mu^+\mu^-)$$

Search Results
Branching Ratio Limits

- Construct a Likelihood Ratio L_R with three discriminating observables.
- Optimize L_R cut on the expected upper limit

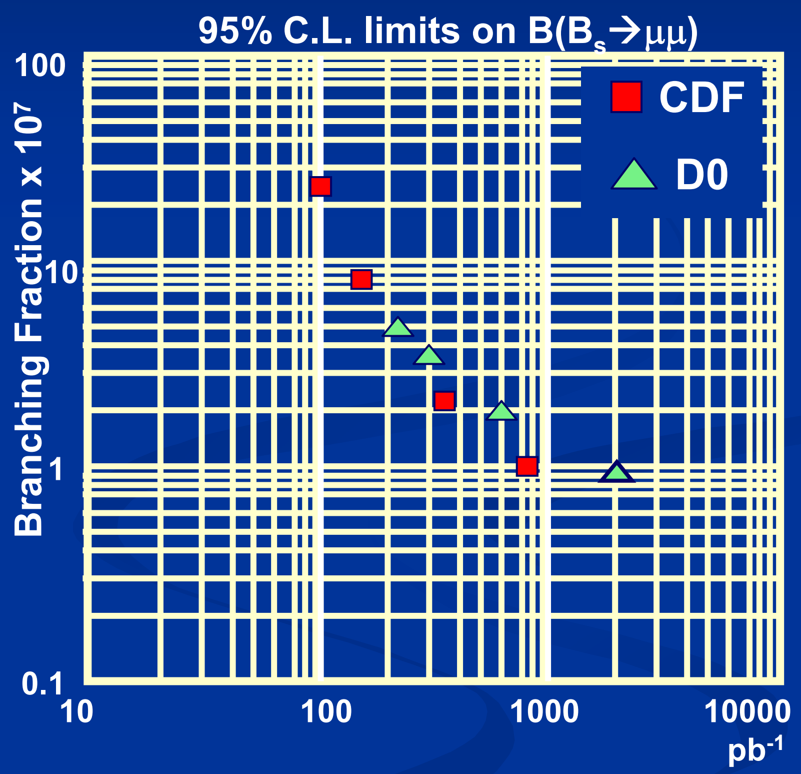
B^0_s search		B^0_d search	
Expect.	Obs.	Expect.	Obs.
1.27±0.37	1	2.45±0.40	2



Int. Lum.	BR ($B_s \rightarrow \mu^+\mu^-$) 90% (95%) C.L.	BR ($B_d \rightarrow \mu^+\mu^-$) 90% (95%) C.L.
780 pb^{-1}	$< 8.0\cdot10^{-8}$(10)	$< 2.3\cdot10^{-8}$(3)

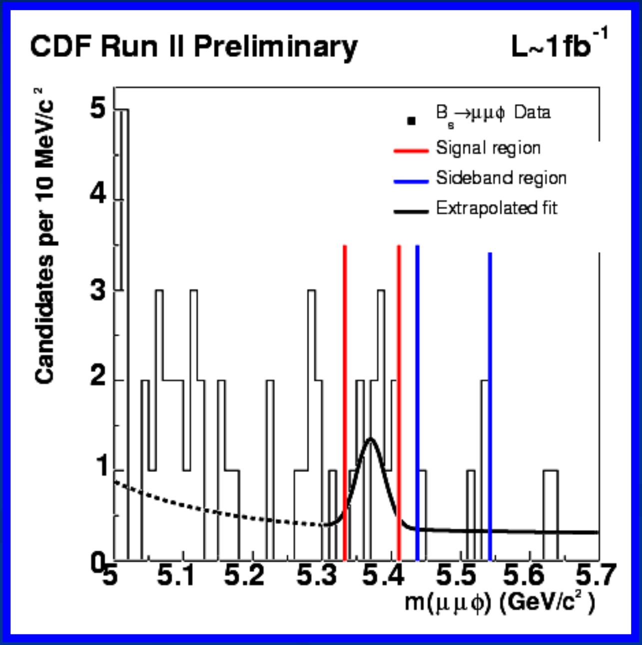
Projected Sensitivity

- Current values entering the 10^{-8} territory
- Ongoing efforts to improve sensitivity of the analyses
- **Any signal at the Tevatron will be evidence of New Physics**



Search for $B^{(+)} \to \mu^+\mu^- h^{(+)}$ $(b \to s\, ll)$

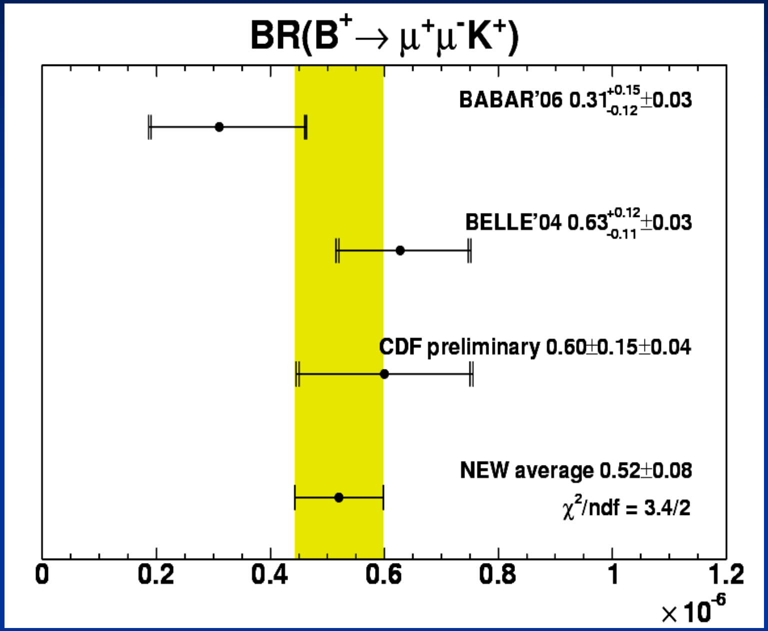
- B_d and B^+ modes established at B-factories
  - **BR** ($B^+ \to \mu\mu\ K^+$)=**$0.34^{+0.19}_{-0.14}$ x 10^{-6}** (PDG 06)
  - **BR** ($B_d \to \mu\mu\ K^{0*}$)=**$1.22^{+0.38}_{-0.32}$ x 10^{-6}** (PDG 06)
- Tevatron: **$B_s \to \mu\mu\phi$** decays
  - **Sensitive to New Physics** via decay rates and decay kinematics
  - $BR(B_s \to \mu\mu\phi)=1.6\times10^{-6}$
- Method: normalize each signal to analogous $B\to J/\psi h$ ($J/\psi\to\mu\mu$)

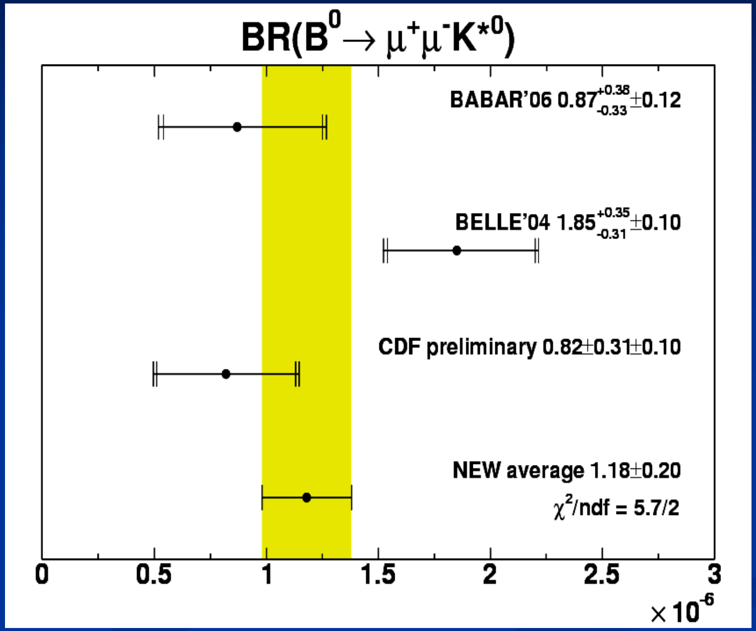


2.4 σ significance

$$\frac{BR(B\to\mu^+\mu^- h)}{BR(B\to J/\psi h)} = \frac{N_{\mu\mu h}}{N_{J/\Psi h}}\frac{\varepsilon^{total}_{J/\Psi h}}{\varepsilon^{total}_{\mu\mu h}} BR(J/\psi\to\mu^+\mu^-)$$

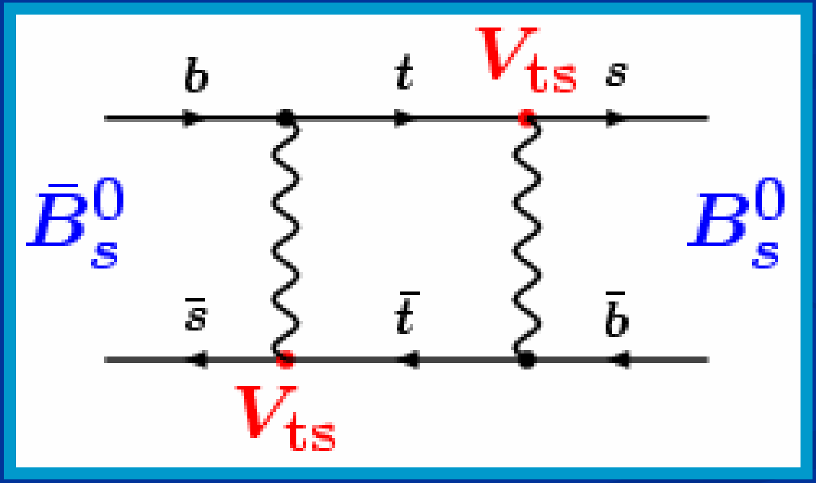
BR (B→μμh)



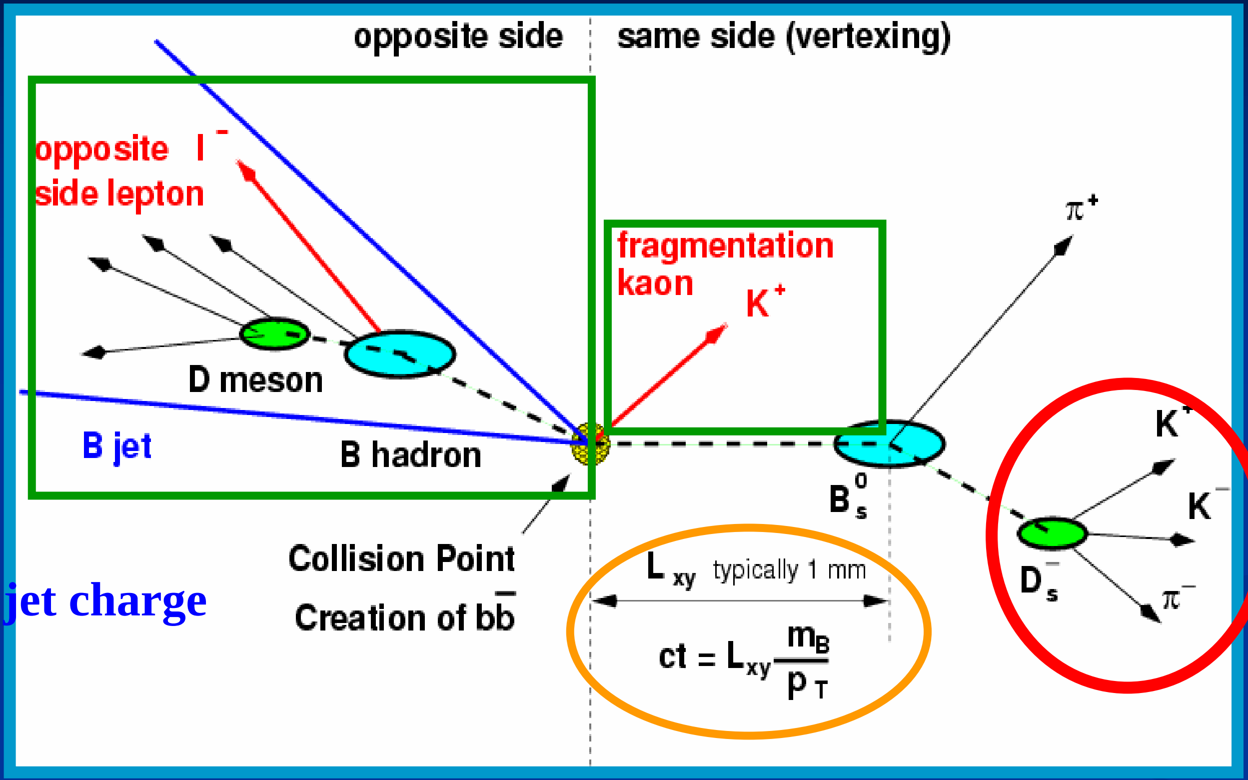


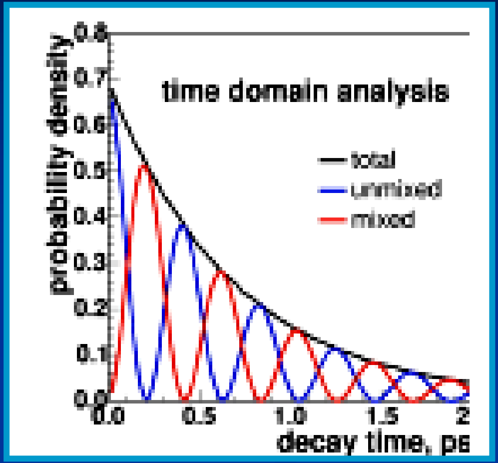
- Good agreement & similar uncertainty with B-factories in μμh
- $BR(B^+ \rightarrow \mu\mu K^+) = [0.72 \pm 0.15(stat.) \pm 0.05(sys.)] x10^{-6}$ (45 ev.)
- $BR(B^0 \rightarrow \mu\mu K^*) = [0.82 \pm 0.31(stat.) \pm 0.10(sys.)] x10^{-6}$ (20 ev.)
- $BR(B_s \rightarrow \mu\mu\phi) < 2.4\ x10^{-6}$ @ 90% C.L.

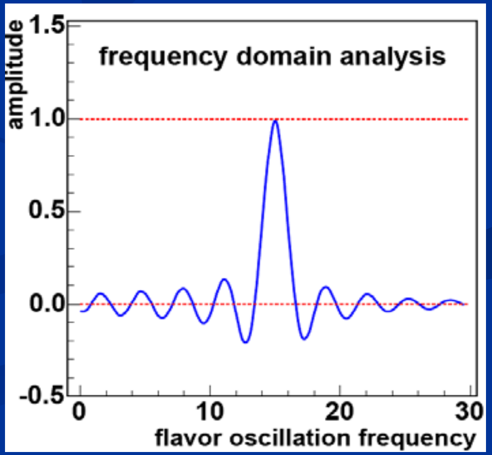
B_s-$\overline{B_s}$ Oscillations



B_s mixing: Method



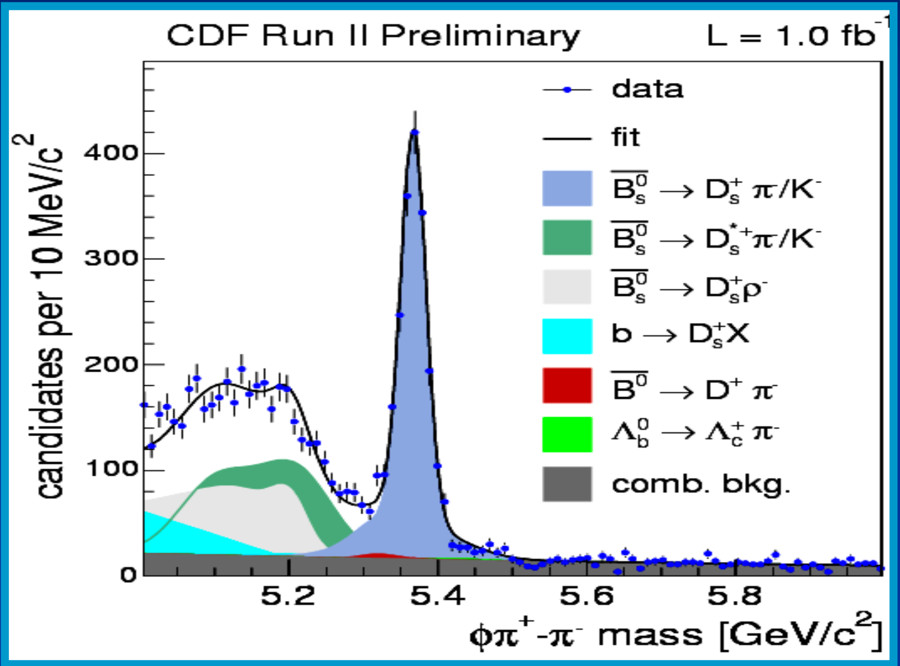


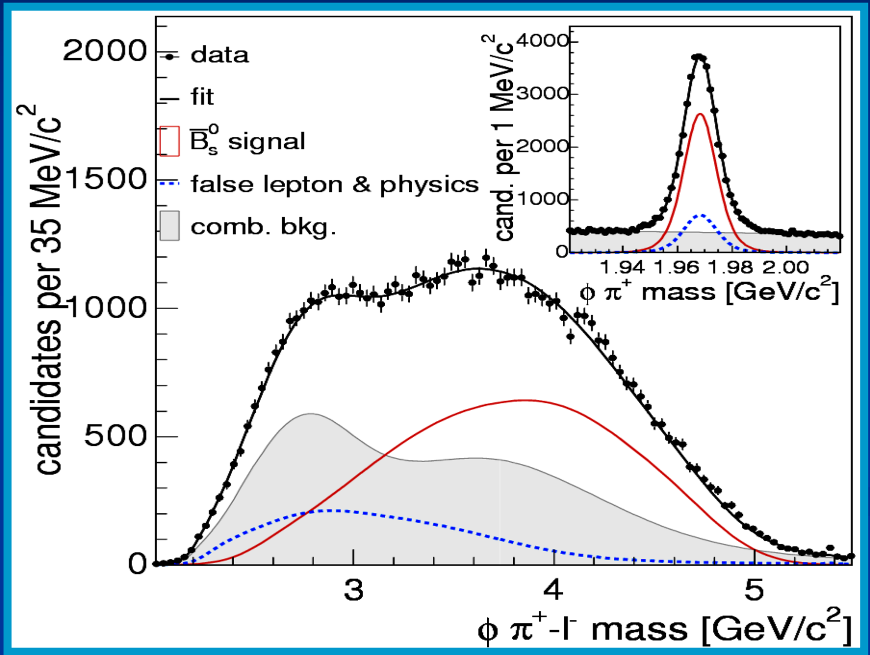


Ingredients to measure mixing:

- Proper decay time ct, B rest frame
- B flavor at production, flavor tagging
- B flavor at decay, final state

Data Samples: hadronic vs semileptonic

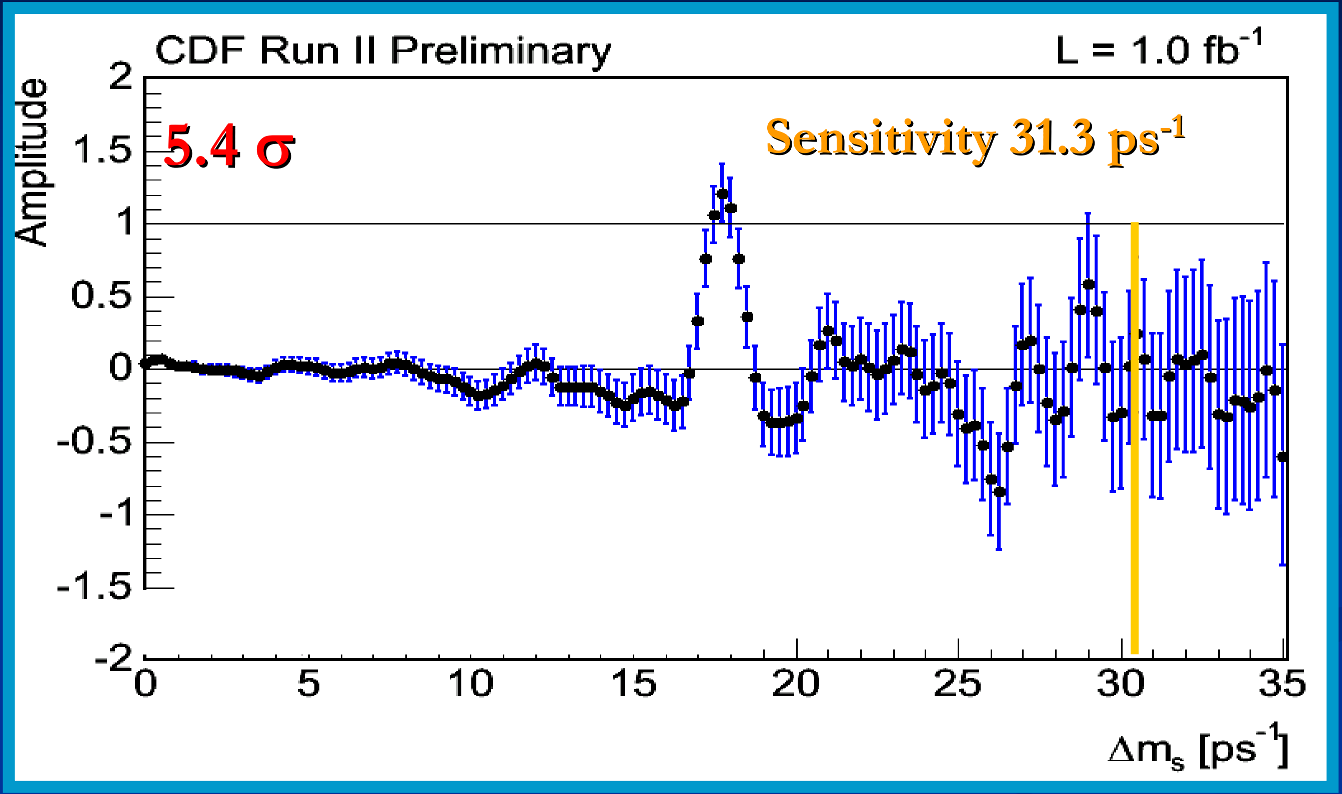




- **Hadronic decays: 8700**
  - $B_s \to D_s \pi(\pi\pi)$
  - great ct, mass resolution
  - small branching ratio

- **Semileptonic: ~61500**
  - $B_s \to l\ D_s\ X$
  - large branching ratio
  - inferior ct, mass resolution

B_s mixing: Result

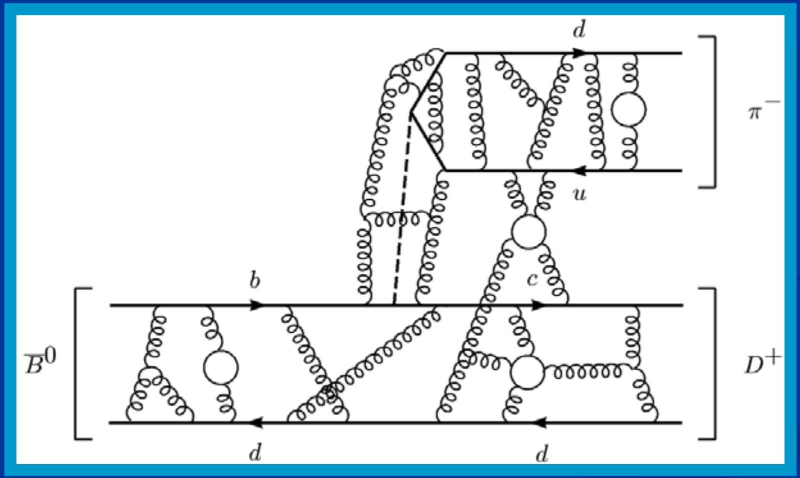


$$\Delta m_s = 17.77 \pm 0.10\,(\text{stat.}) \pm 0.07\,(\text{syst.})\ \text{ps}^{-1}$$ (2.83 THz)

Combined with Δm_d

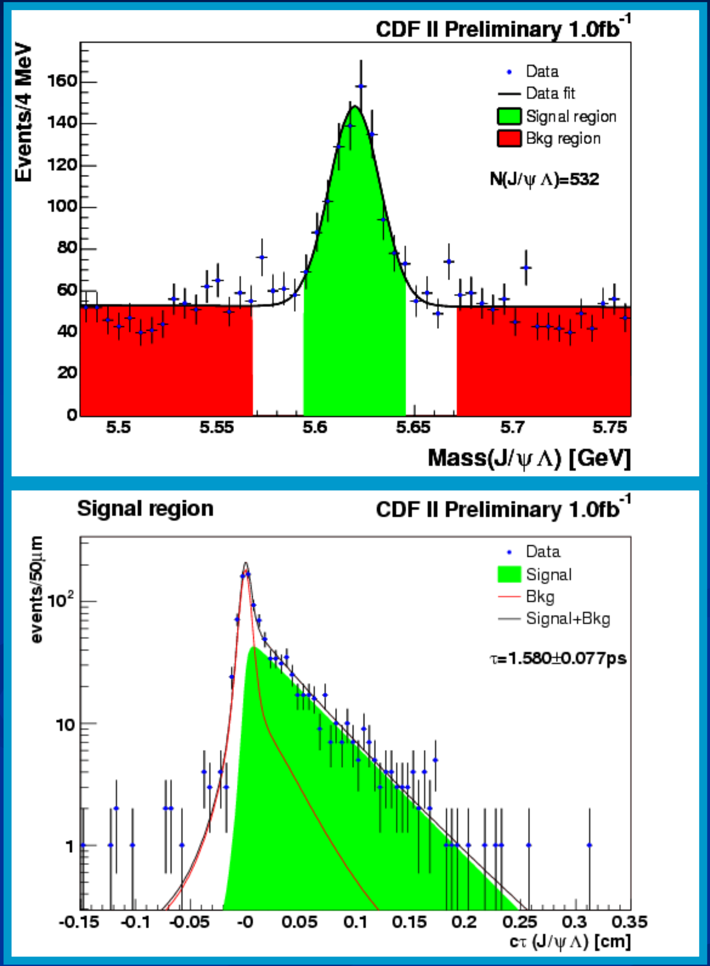
$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2060 \pm 0.0007\,(\text{exp.})^{+0.0081}_{-0.0060}\,(\text{theo.})$$

Lifetime measurements



Λ_b Lifetime

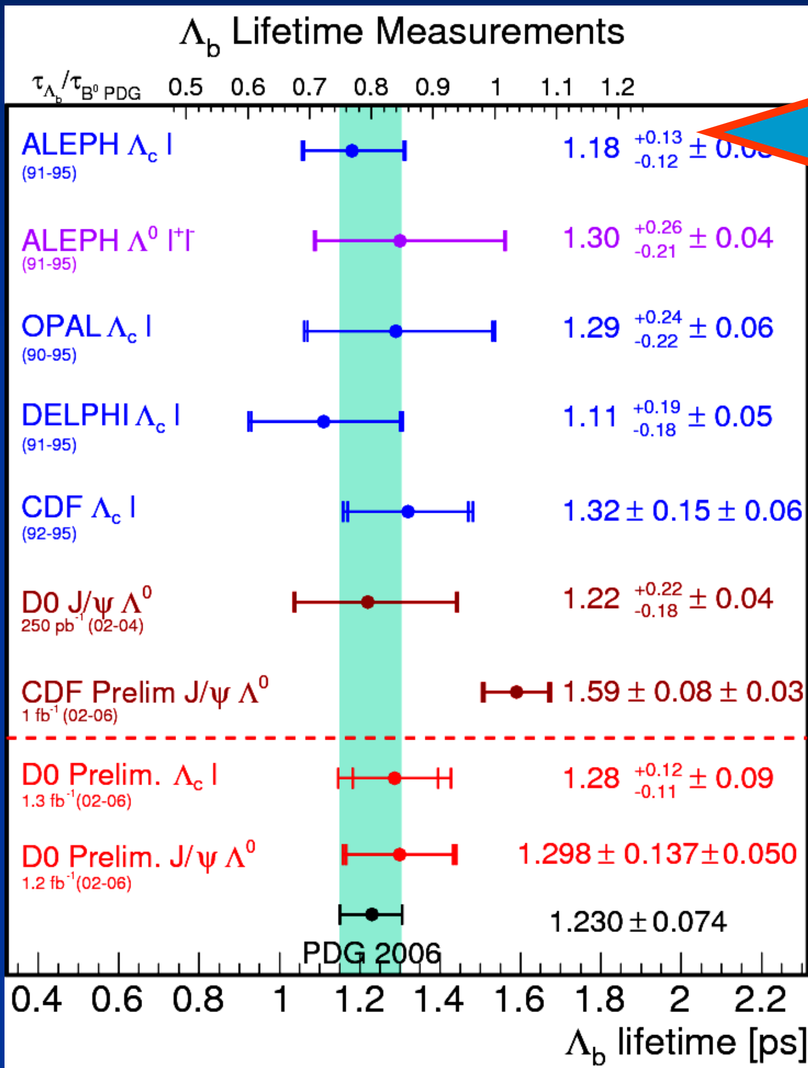
- Going back to first measurements at LEP, $\tau(\Lambda_b)$ has been low compared to HQET expectations.
  - For $\tau(\Lambda_b)/\tau(B^0)$, early theory predictions (~0.94) and experiment differed by more than $2\sigma \Rightarrow$ "Λ_b lifetime puzzle"
  - Current NLO QCD + $1/m_b^4$ calculation:
    $\tau(\Lambda_b)/\tau(B^0) = 0.86 \pm 0.05$
    consistent w/HFAG 2005 world avg:
    $\tau(\Lambda_b)/\tau(B^0) = 0.803 \pm 0.047$
  - Experimental sensitivity dominated by semileptonic Λ_b measurements
- Measured with fully reconstructed $\Lambda_b \rightarrow J/\psi\ \Lambda^0$ decay



$\tau(\Lambda_b) = 1.551 \pm 0.019$ (stat.) ± 0.011 (syst.) ps

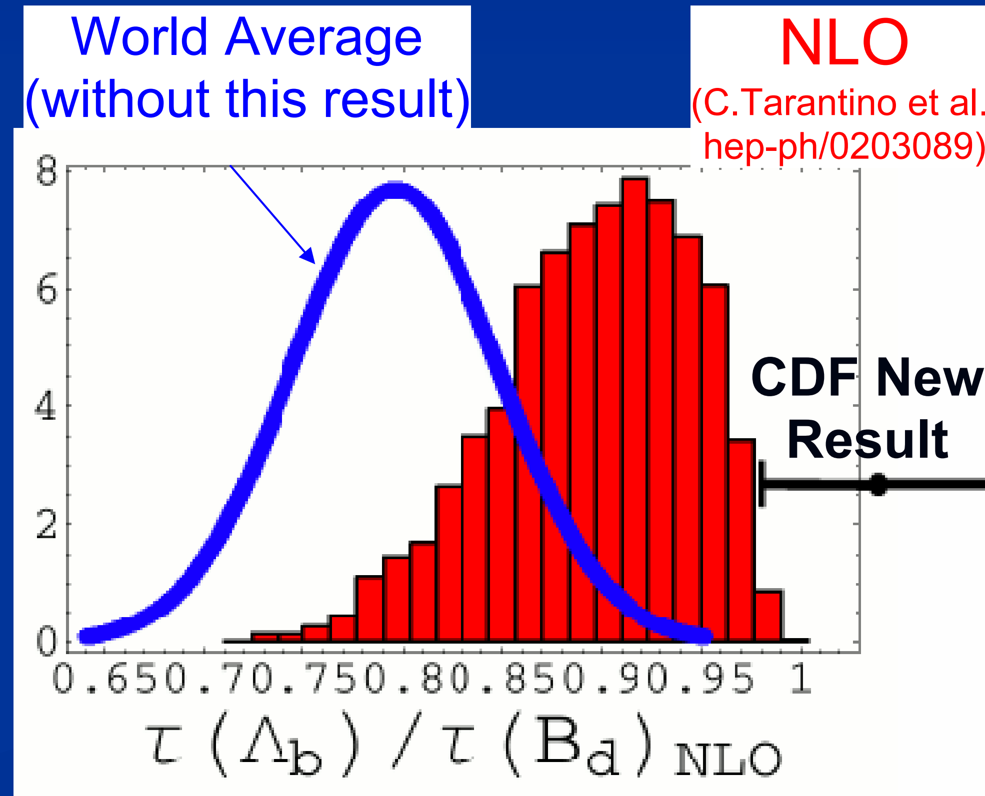
$\tau(\Lambda_b)/\tau(B^0) = 1.018 \pm 0.062$ (stat.) ± 0.007 (syst.)

Λ_b Lifetime vs theory

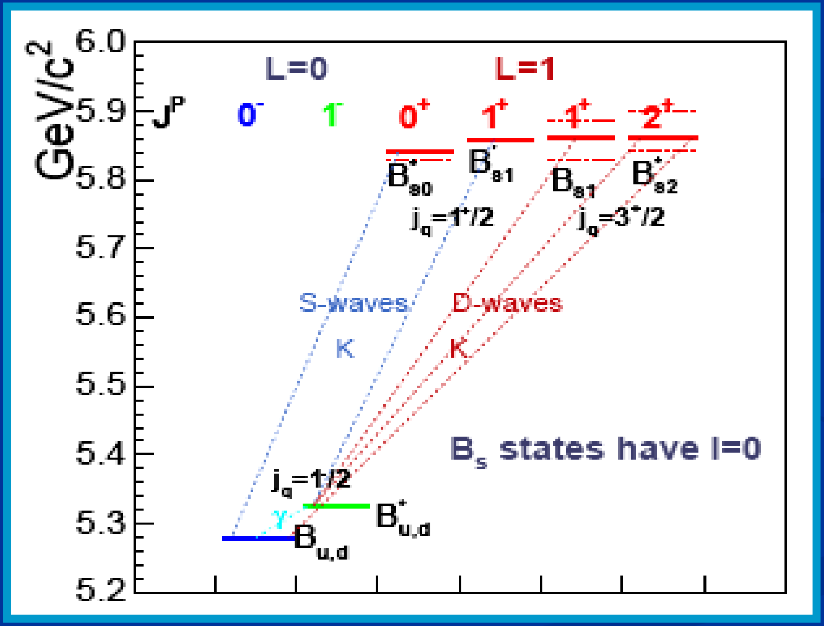


As precise as world average

~ 3 σ different though!

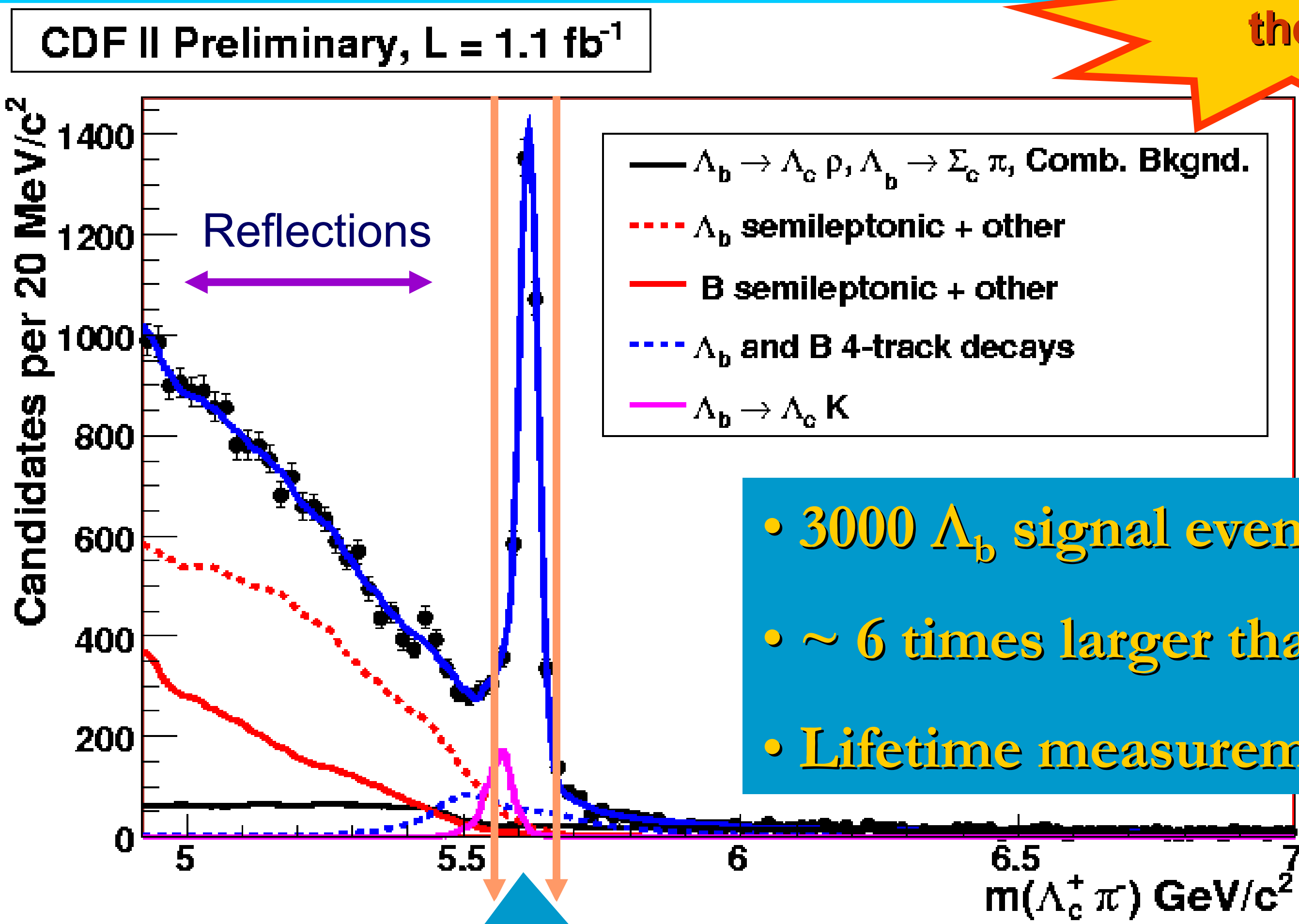


Spectroscopy



Sample $\Lambda_b \to \Lambda_c \pi$

Largest in the World!

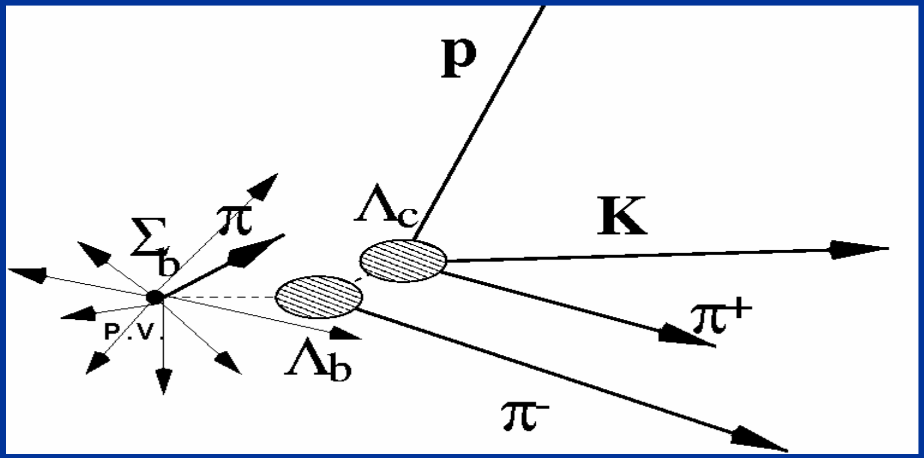


- 3000 Λ_b signal events
- ~ 6 times larger than $J/\psi\ \Lambda$
- Lifetime measurement in progress

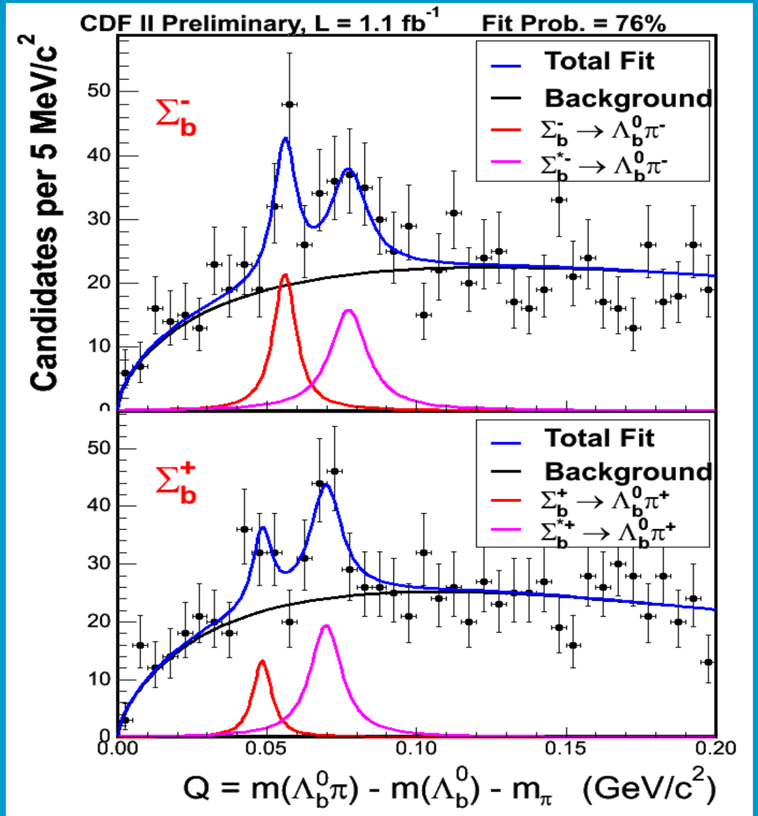
Signal region: [5.565, 5.670]

N (Λ_b)	86 %
N (B)	10 %
comb	4 %

Observation of $\Sigma_b^{(*)} \to \Lambda_b \pi$

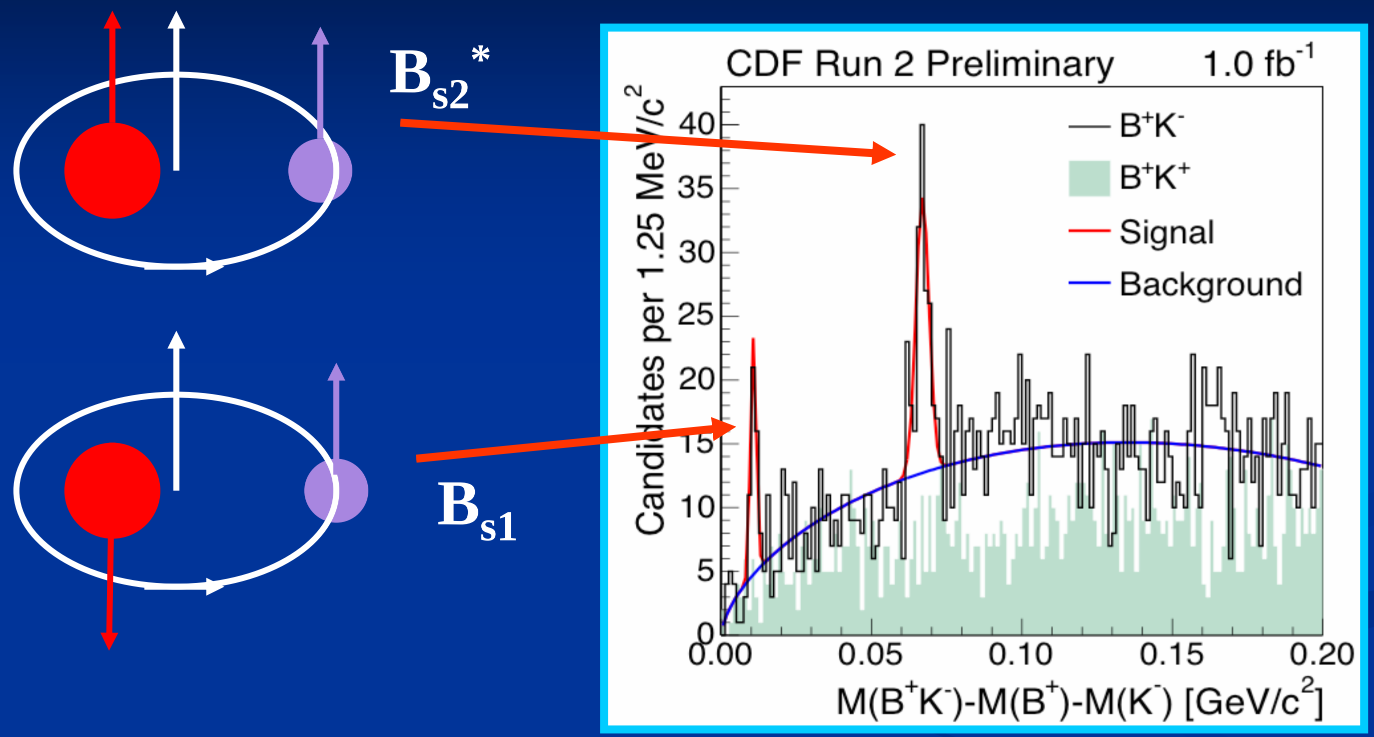


- *b*-quark discovered in 1977
- Wealth of b-mesons is found
- Only one b-baryon Λ_b in PDG 2006
- Found 4 $\Lambda_b\pi$ resonances consistent with lowest lying charged Σ_b states
- significance > 5σ



$$m(\Sigma_b^-) - m(\Lambda_b^0) - m_\pi = 55.9^{+1.0}_{-1.0}\ (\text{stat}) \pm 0.1\ (\text{syst})\ \text{MeV}/c^2$$
$$m(\Sigma_b^+) - m(\Lambda_b^0) - m_\pi = 48.4^{+2.0}_{-2.3}\ (\text{stat}) \pm 0.1\ (\text{syst})\ \text{MeV}/c^2$$
$$m(\Sigma_b^*) - m(\Sigma_b) = 21.3^{+2.0}_{-1.9}\ (\text{stat})\ ^{+0.4}_{-0.2}\ (\text{syst})\ \text{MeV}/c^2$$

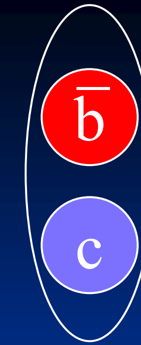
Orbitally Excited B_s-mesons

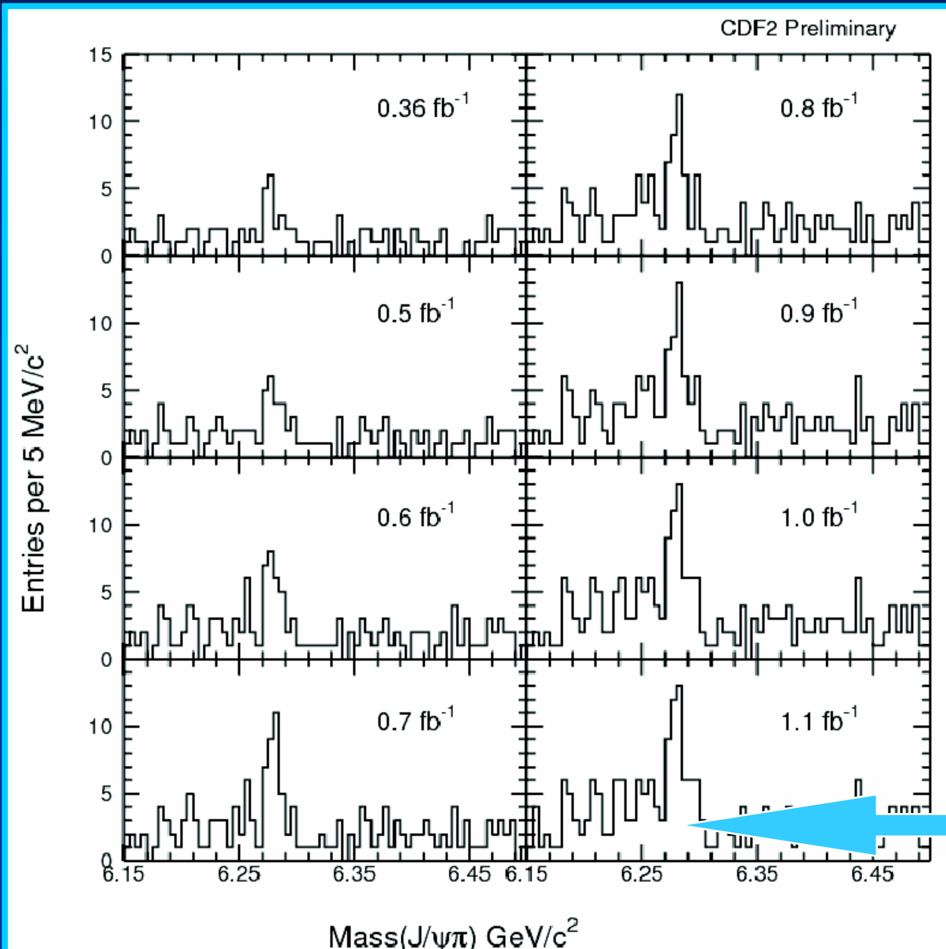


Two signals:

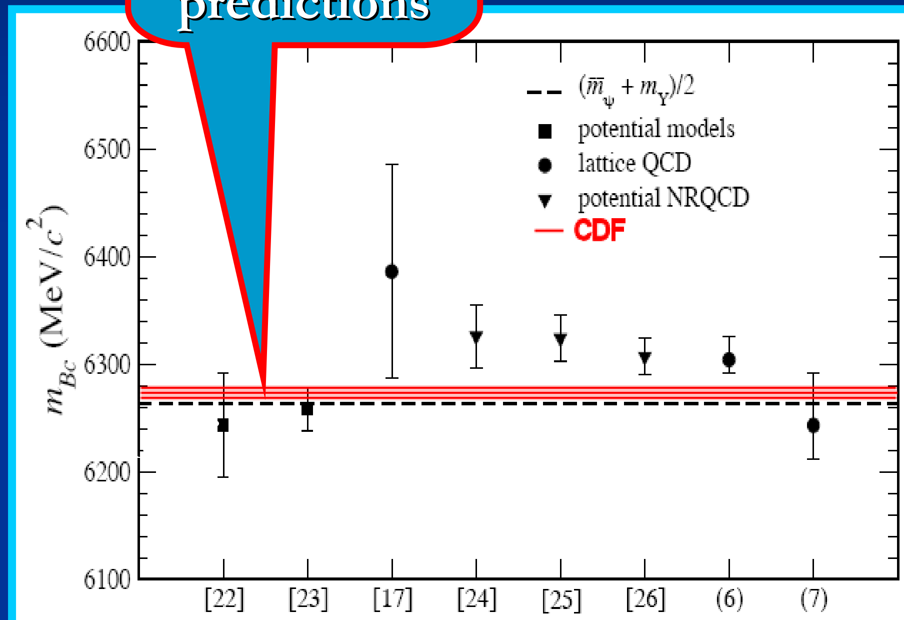
- B^*_{s2} already seen by OPAL, DELPHI and DØ
- B_{s1} $\Rightarrow$ first observation!

$B_c^{\pm} \to J/\psi\, \pi^{\pm}$





Challenges theoretical predictions



$N(B_c) = 45.2 \pm 9.4$, $S/\sqrt{B} = 7.5$

$m(B_c) = 6276.5 \pm 4.0$ (stat) $\pm$ 2.7(syst) MeV/c^2

Topics Not Covered

CP Violation:
Acp(B→hh),
Acp(D^0→Kp), …

New particles:
X(3872), B** …

Bs lifetime difference
($\Delta\Gamma_s$)

More info on

www-cdf.fnal.gov

Production properties:
$\sigma(b)$, $\sigma(J/\psi)$, $\sigma(D^0)$, …

Mass measurements:
B_c, Λ_b, B_s, …

Rare decays:
$D^0 \rightarrow \mu^+\mu^-$, …

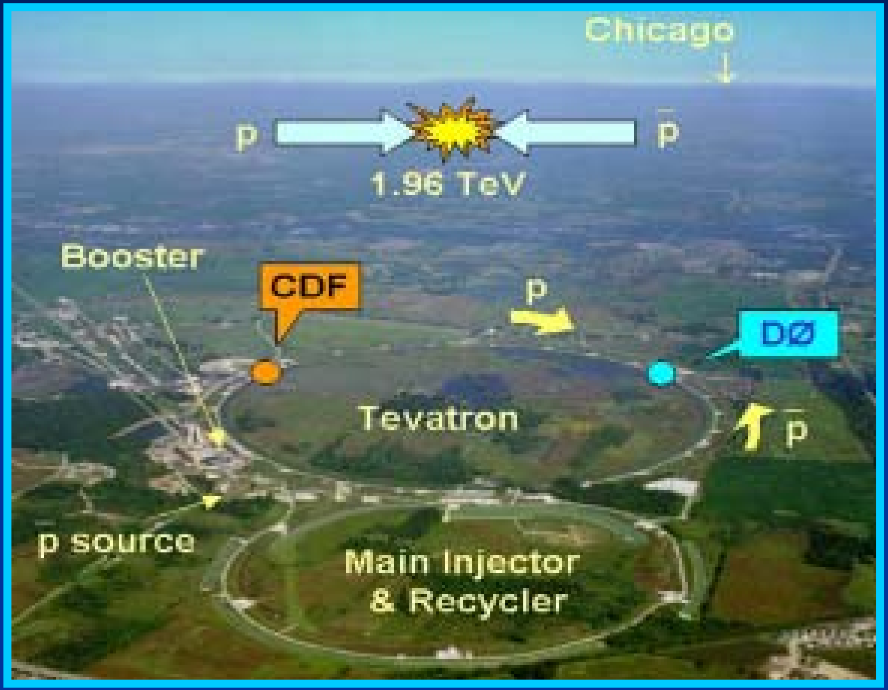
B_s mixing phase (ϕ_s)

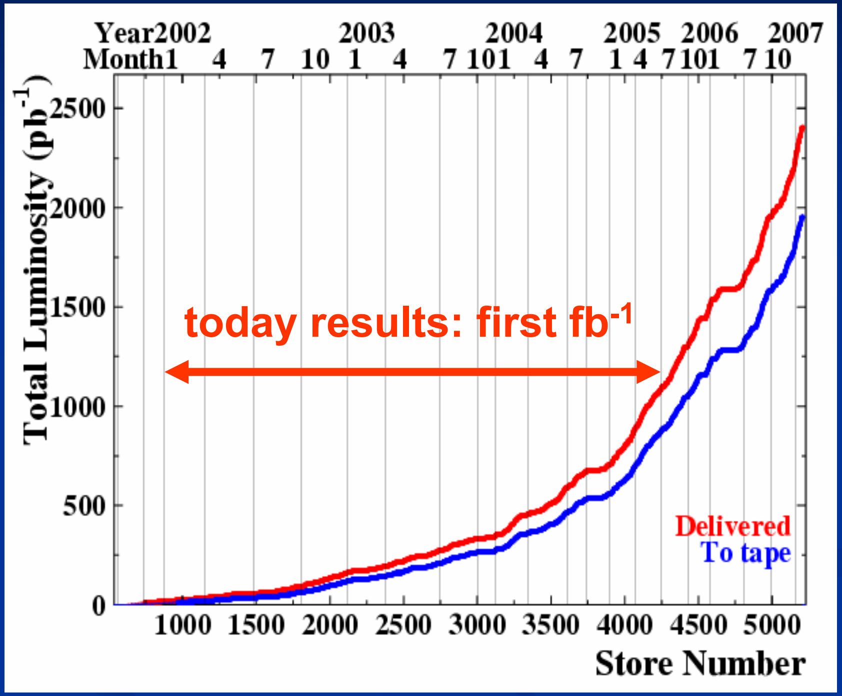
Conclusions

- The B program at the Tevatron has been an incredibly fruitful endeavor.
- The program is complementary to and competitive with e^+e^- B factories
- We expect several fb^{-1} by the end of the Run II.
- With more data more precision measurements and new discovery potential

BACKUP

Tevatron





- Excellent performance of Tevatron in last years
- Record Instantaneous luminosity > 2×10^{32} cm^{-2} s^{-1}
- Now: delivered $\int L dt = 2.4$ fb^{-1}
- Good for b-physics on tape $\int L dt = 1.6$ fb^{-1}

The CDF II detector

96 layer drift chamber

$44 < r < 132$ cm, $|z| < 155$ cm

$|\eta| \leq 1.0$, 30k channels

silicon layers:

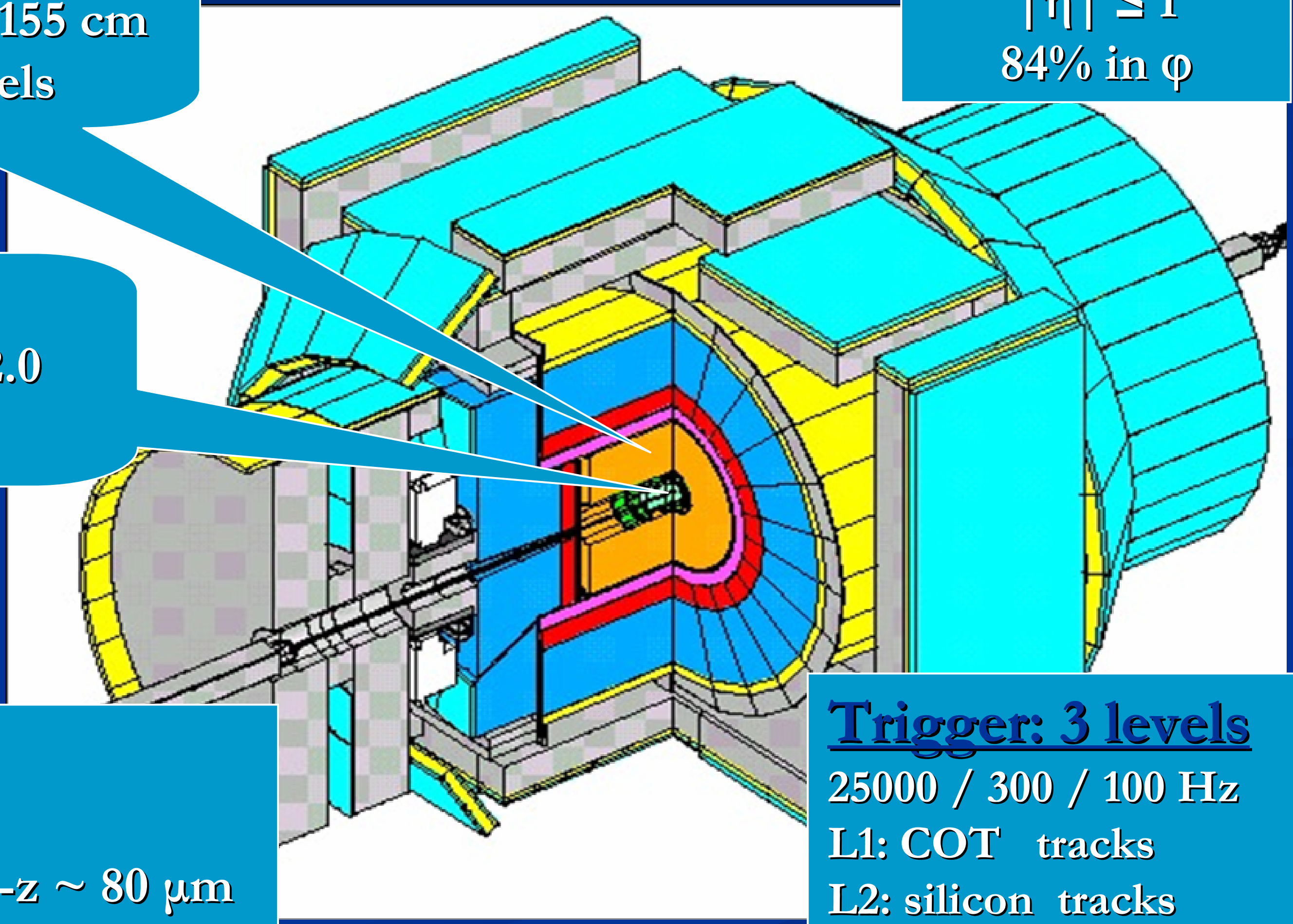
90 cm long, $|\eta| \leq 2.0$

$r_{00} = 1.3 \div 1.6$ cm

μ coverage

$|\eta| \leq 1$

84% in φ



Resolution:

$p_T \sim 0.15\%\ p_T$

vertex r-φ ~ 30 μm ; r-z ~ 80 μm

J/ψ mass ~14 MeV/c^2

Trigger: 3 levels

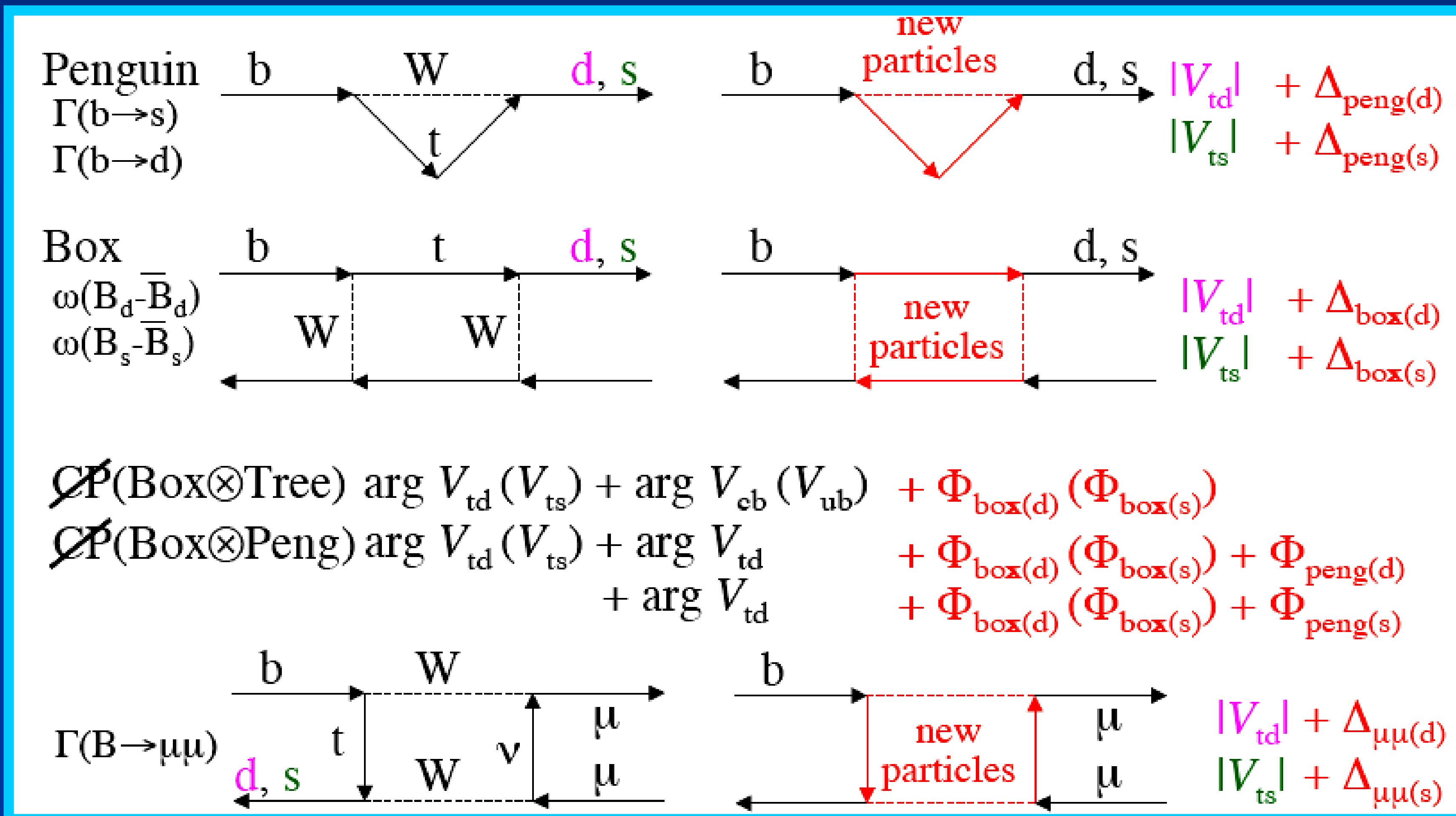
25000 / 300 / 100 Hz

L1: COT tracks

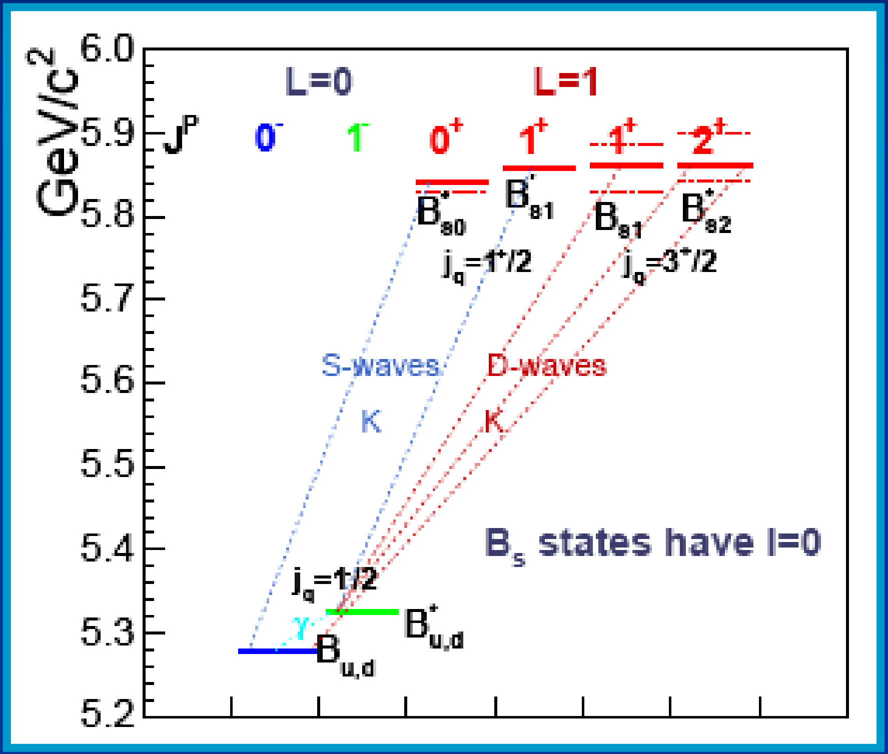
L2: silicon tracks

dead time < 5%

SM Precision measurements ⇒ indirect search for new Physics



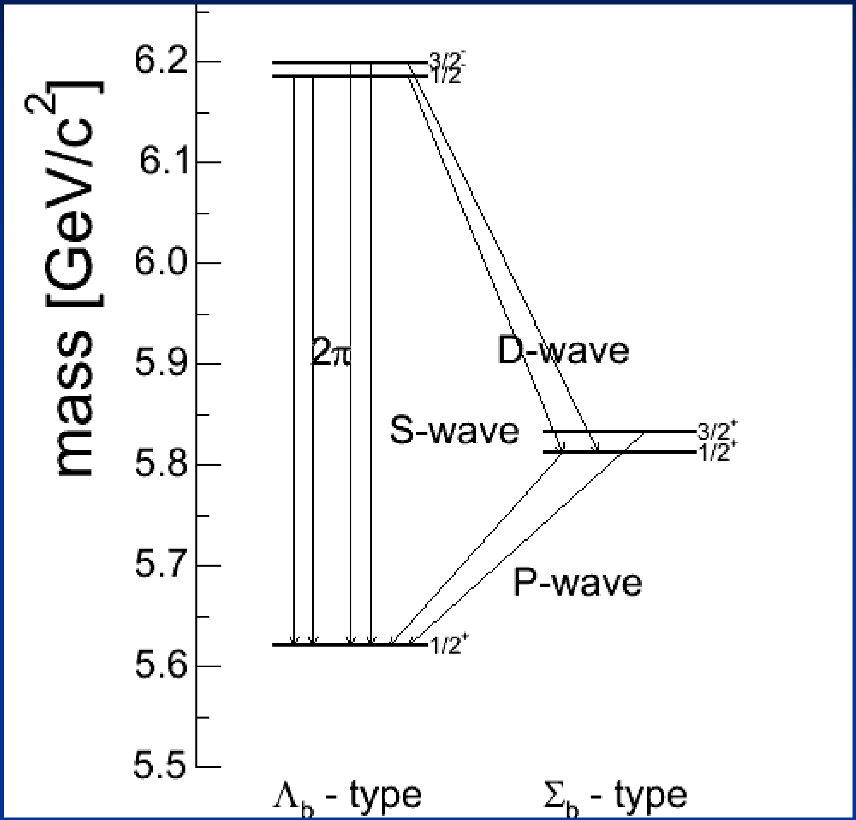
Orbitally Excited B_{sJ} Mesons



j_q	J^P	B_s^*	Decay	Width
1/2	0^+	B_{s0}	BK	Broad (S-wave)
1/2	1^+	B_{s1}	B*K	Broad (S-wave)
3/2	1^+	B_{s1}	B*K	Narrow (D-wave)
3/2	2^+	B_{s2}^*	BK, B*K	Narrow (D-wave)

- $B^{*+} \rightarrow B^+\gamma$, where γ is undetected
- Shift of possible B_{s2}^*, B_{s1} peaks by $\Delta M(B^{**} - B^+) = 45.78$ MeV/c^2 (see PDG)
- Two channels: $B^+ \rightarrow J/\psi K$, $B^+ \rightarrow D\pi$

Σ_b Motivation



- Λ_b only established *B* baryon
- Enough statistics at Tevatron to probe other heavy baryons
- Next accessible baryons:

Σ_b: b{qq}, q = u,d;

$$J^P = S_Q + s_{qq}$$

$= 3/2^+(\Sigma_b^*)$

$= 1/2^+(\Sigma_b)$

Σ_b property	Expected values (MeV/c^2)
m(Σ_b) - m(Λ_b^0)	180 – 210
m(Σ_b^*) - m(Σ_b)	10 – 40
m(Σ_b^-) - m(Σ_b^+)	5 – 7
$\Gamma(\Sigma_b), \Gamma(\Sigma_b^*)$	~8, ~15

- *HQET extensively tested for Qq systems; interesting to check predictions for Qqq systems*
- *Baryon spectroscopy also tests Lattice QCD and potential quark models*

Hadronic sample

B_s decay	Signal
$D_s(\varphi\pi)\pi$	2000
Partially rec.	3100
$D_s(K^*K))\pi$	1400
$D_s(3\pi))\pi$	700
$D_s(\varphi\pi)3\pi$	700
$D_s(K^*K))3\pi$	600
$D_s(3\pi))3\pi$	200
Total	**8700**