CDF Run-II 実験の最近の結果

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東京理科大学　野田キャンパス

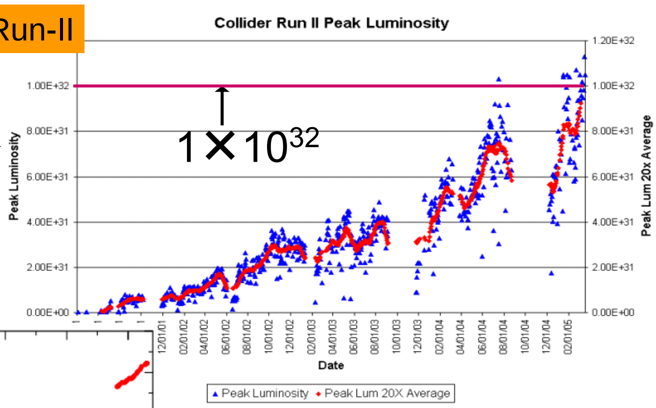
Tevatron Accelerator

- New 120/150 GeV Main Injector replaced Main Ring
  - Higher intensity of protons and antiprotons.
- Tevatron operates with 36 x 36 bunches (had been 6 x 6)
- Increased CM energy 1.8 TeV to 1.96 TeV

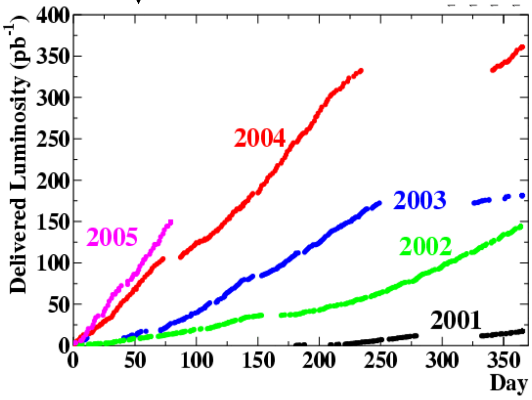
Run II started in March 2001

Tevatron Luminosity : Run-II

瞬間ルミノシティ

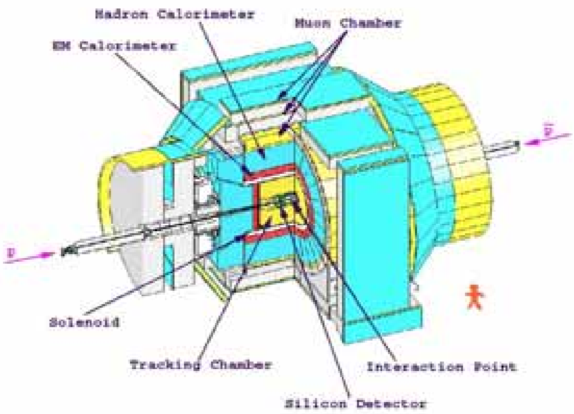


年ごとの積分値



- Peak luminosity
  1.24 x 10^{32} cm^{-2} s^{-1}
  (Mar 21, 2005)
- Delivered luminosity
  ~ 850 pb^{-1}
- Recorded luminosity
  ~ 660 pb^{-1}

Run-II CDF Detector



Many detector components are brand-new

- Tracking system
  - Silicon detectors
  - Main drift chamber
- FE electronics
- Trigger/DAQ
- Plug calorimeter
- Extended muon coverage
- TOF system

Retained good momentum resolution & lepton ID.

最新の物理の結果

- **電弱相互作用** (W boson **の質量**, Gauge boson **対生成**)
- Top quark **の物理** (**生成断面積**, **質量**, W helicity)
- Higgs **粒子の探索** (**3つのチャンネル**)
- *B* **粒子の物理** (b → s **遷移を主に**)

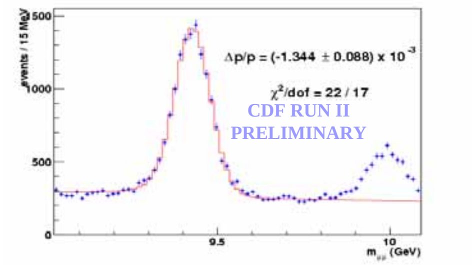
あらゆる結果を網羅することは不可能

http://www-cdf.fnal.gov/
を参照されたし.

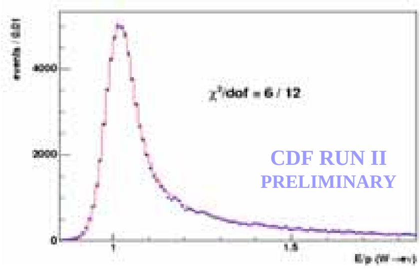
Electroweak Physics

$W^{\pm}$ boson mass

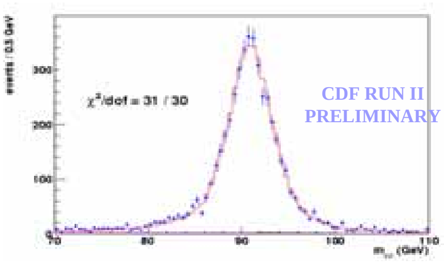
p scale: J/ψ, $\Upsilon \to \mu^+\mu^-$

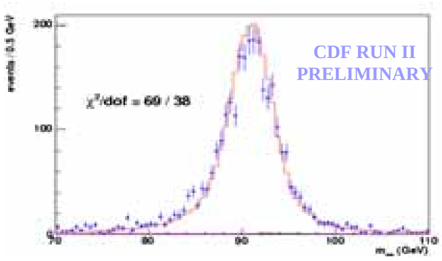


E scale: E/p in $W \to e\nu$



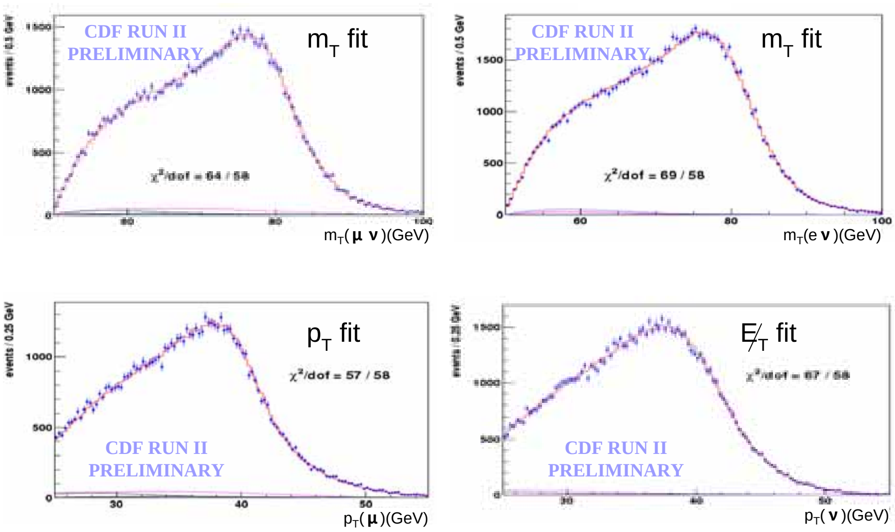
$Z^0 \to \mu^+\mu^-$ and $\to e^+e^-$: check p and E scales





W Mass Measurement

Muons Electrons



Fits still blinded

W boson 質量測定の誤差

CDF RUN II PRELIMINARY

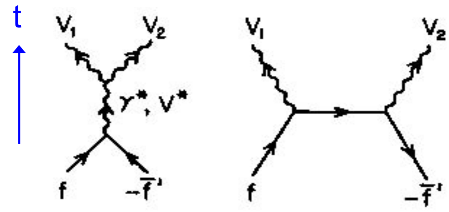
Source	Electrons Run II (Run Ib)	Muons Run II (Run Ib)
Systematic		
Lepton energy scale and resolution	70 (80)	30 (87)
Recoil scale and resolution	50 (37)	50 (35)
Backgrounds	20 (5)	20 (25)
Production and decay model	30 (30)	30 (30)
Statistics	45 (65)	50 (100)
Total	105 (110)	85 (140)

Total uncertainty (76 MeV) already lower than Run 1 (79 MeV)

質量の中心値 → 夏までに公表の予定

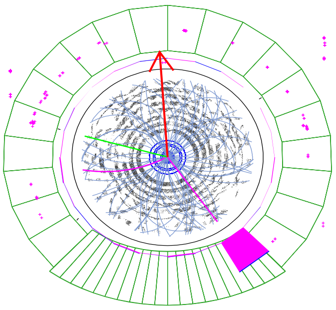
Gauge boson pair production

Unified electroweak theory :
Non-Abelian gauge structure.
$\rightarrow$ self-coupling among gauge bosons.



$\bar{p}p \rightarrow W^+W^-X \rightarrow (\ell^+\nu)\,(\ell'^-\,\bar{\nu})X$

2 enegetic leptons, large missing E_T, no jets.

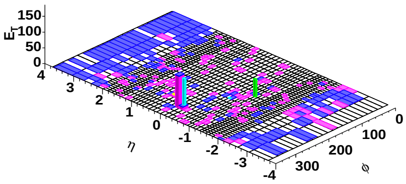


Run 162175 Event 1550545 : $WW \rightarrow e^+\nu_e\mu^-\bar{\nu}_\mu$ Candidate

$p_T(e) = 112.7$ GeV/c; $p_T(\mu) = 57.0$ GeV/c; $M_{e\mu} = 165.6$ GeV

$\not{E}_T = 86.8$ GeV; $\Phi(\not{E}_T) = 1.6$

$\Delta\Phi(\not{E}_T, \text{lepton}) = 1.2$; $\Delta\Phi(e,\mu) = 2.4$; Opening-Angle(e^+, e^-)=1.9

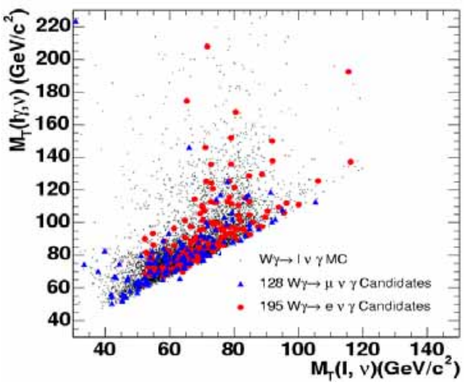


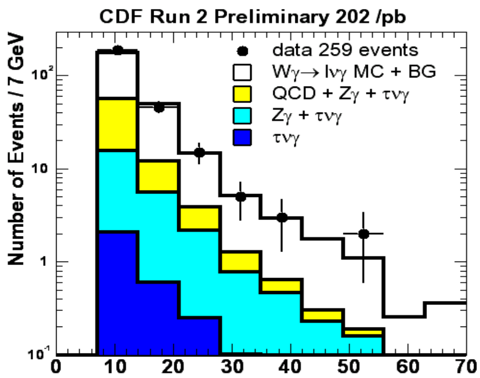
CDF : $\sigma(\bar{p}p \rightarrow W^+W^-) = 14.3^{+5.6}_{-4.9} \pm 1.6 \pm 0.9$ pb
(12.5 ± 0.9 pb theory)

W + Photon Production

Photons detected > 7 GeV
Check 3-body mass (l ν γ) for brems.

谷本奈穂 博士論文 （岡山大学）
($W \rightarrow \mu\nu$ channel)

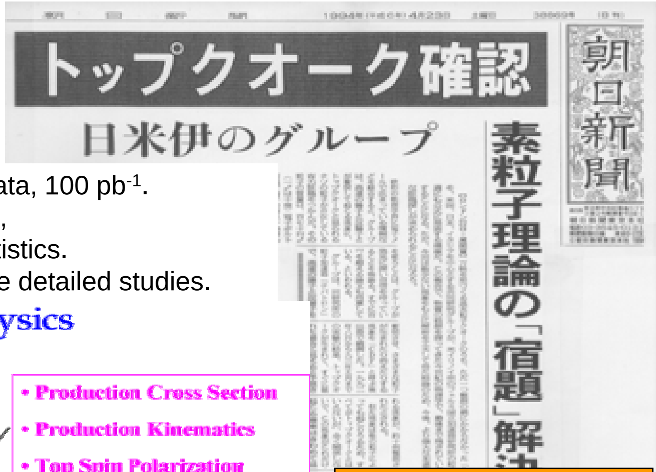




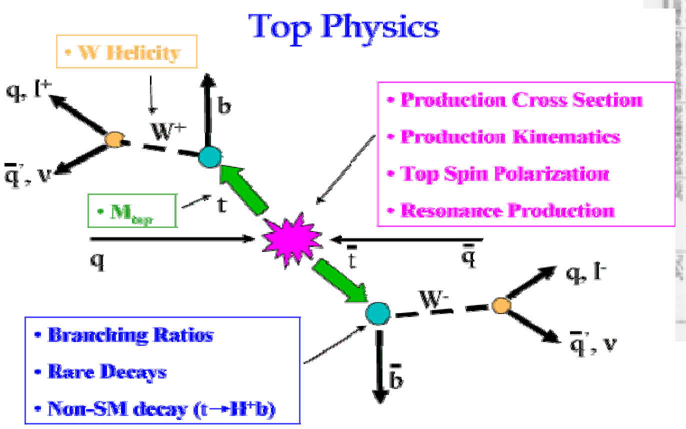
$$\sigma(\bar{p}p \rightarrow W\gamma X)\cdot\mathcal{B}(W \rightarrow \ell\nu) = \begin{cases} 19.7 \pm 1.7 \pm 2.0 \pm 1.1 \text{ pb} & \text{(CDF)} \\ 19.3 \pm 1.4 \text{ pb} & \text{(Theory)} \end{cases}$$

More direct test : angular distributions $\rightarrow$ radiation amplitude zero

Top Quark


トップクオーク確認
日米伊のグループ
素粒子理論の「宿題」解決
朝日新聞

- Observed by CDF in Run-I data, 100 pb^{-1}.
- Tens of events reconstructed, measurements limited by statistics.
- Run-II data should allow more detailed studies.



Signature :
- Two W and two b
- W to lepton + ν or, W to quarks.
- b-jets tagged with lifetime or lepton.

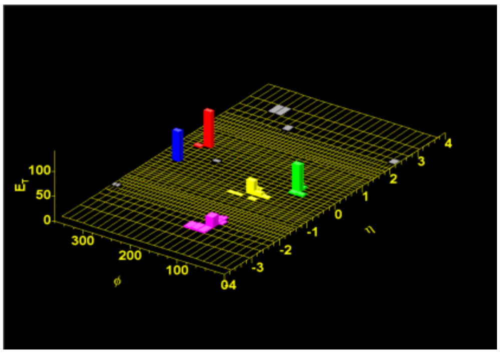
Top quark production cross section

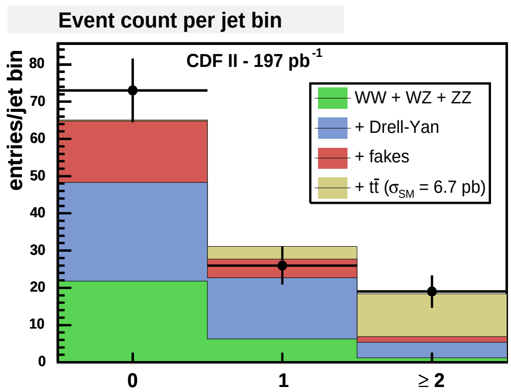
Di-lepton channel

CDF 197 pb^{-1}

$\bar{p}p \to t\bar{t}X \to W^+W^-b\bar{b} \to (\ell^+\nu)\,(\ell'^-\bar{\nu})\,b\bar{b}$,
two leptons and two jets from b quarks.

Jet multiplicity distribution

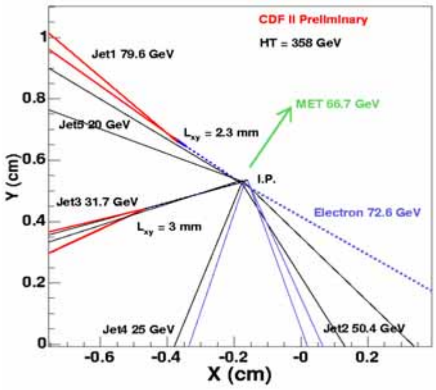




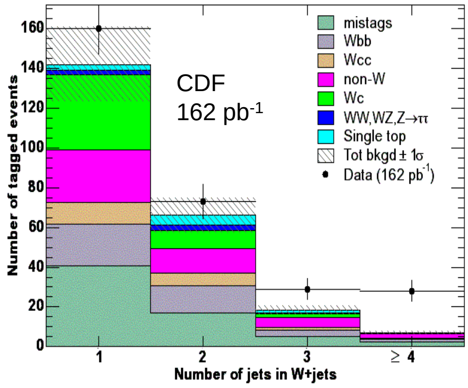
$$\sigma(\bar{p}p \to t\bar{t}X) = 7.0\,^{+2.7}_{-2.3}\,^{+1.5}_{-1.3} \pm 0.4 \text{ pb}.$$

Top cross section

$\bar{p}p \to t\bar{t}X$, $W \to \ell\nu$, $W \to q\bar{q}'$,
b-jets tagged with secondary vertices.



生成点付近の拡大図



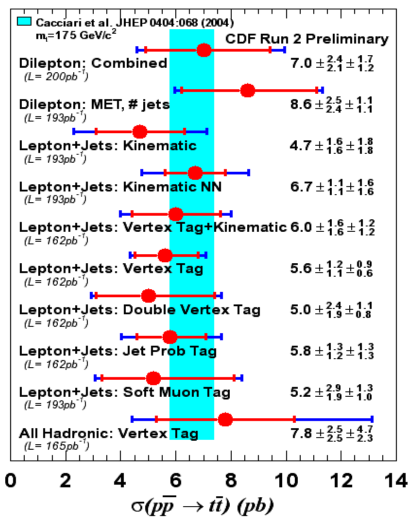
Jet の数の分布

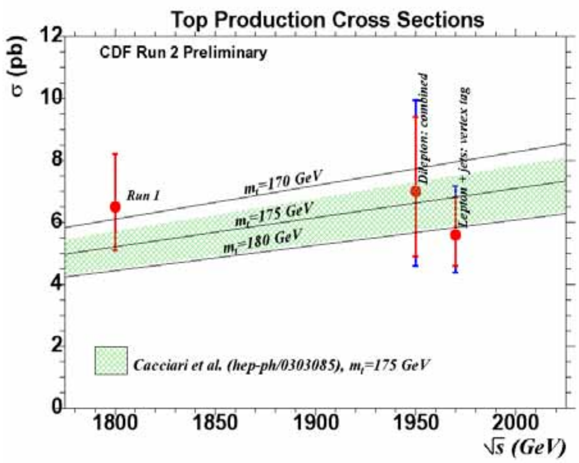
$$\sigma(\bar{p}p \to t\bar{t}X) = 5.6\,^{+1.2}_{-1.0}\,^{+1.0}_{-0.7}\ \text{pb}$$

Many other measurements with various techniques.

$t\bar{t}$ Production Cross Section

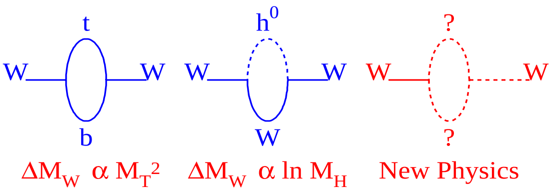
Many channels and techniques.



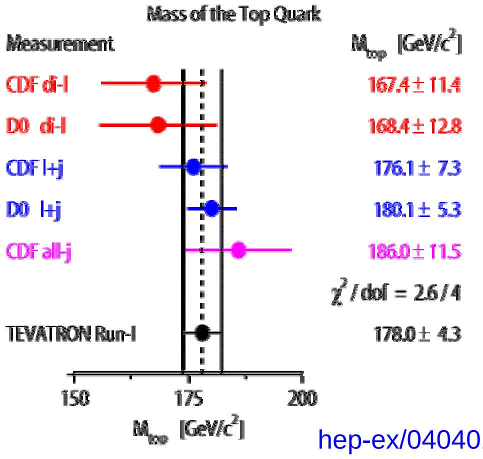


Top Quark Mass

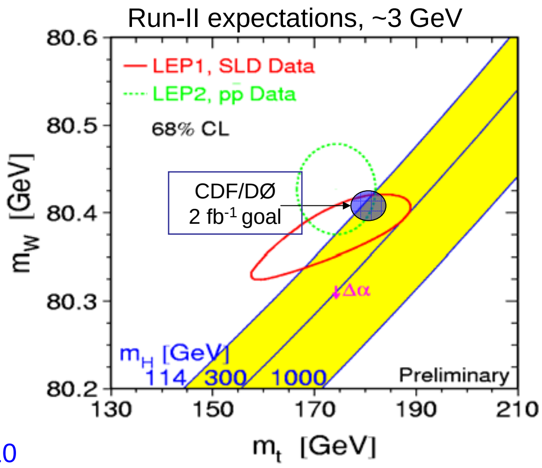
Combine with W mass,
probe Higgs indirectly.



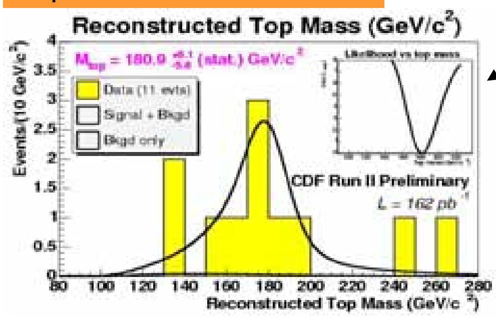
World average : Run I only



hep-ex/0404010



Top mass measurements



Both b-quark jets tagged

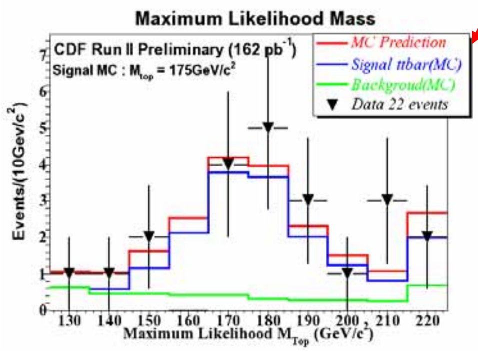
$m_t = 177.2^{+4.9}_{-4.7} \pm 6.6\ \mathrm{GeV}/c^2$

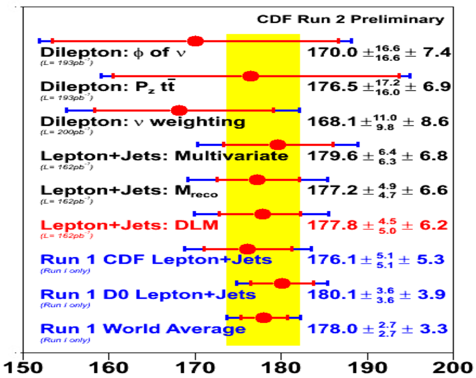
佐藤構二 博士論文 （筑波大学）

Dynamical likelihood method
(K. Kondo, J.Phys.Soc.Jap. 57, 4126,1988)

$m_t = 174.9^{+4.5}_{-5.0} \pm 6.2\ \mathrm{GeV}/c^2$

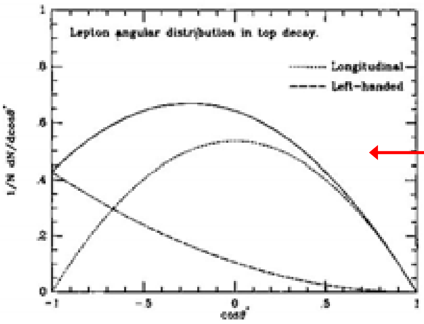
寄田浩平 博士論文 （早稲田大学）





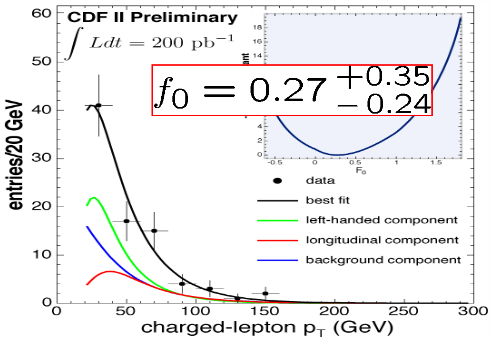
W helicity in top decays

either left-handed (W_L) or longitudinally polarized (W_0)

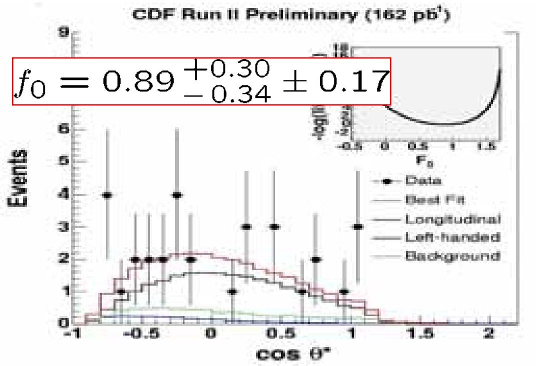


$$f_0 \equiv \frac{\Gamma(t \to b\,W_0)}{\Gamma(t \to b\,W_0) + \Gamma(t \to b\,W_L)} = \frac{m_t^2}{m_t^2 + 2\,m_W^2}$$
$$= 0.70 \quad \text{for} \quad m_t = 175 \quad \text{GeV}/c^2$$

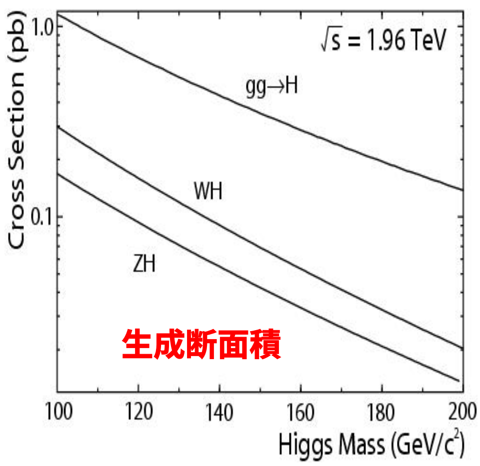
Lepton angular distribution in
W rest frame :
Backward peak for left-handed W.
→ smaller momentum in lab.

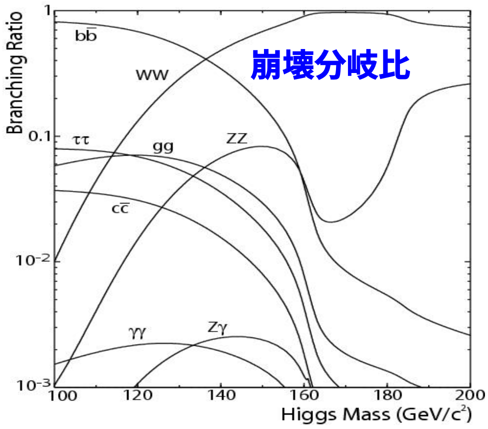


Also reconstructs cosθ*



Higgs 粒子の探索





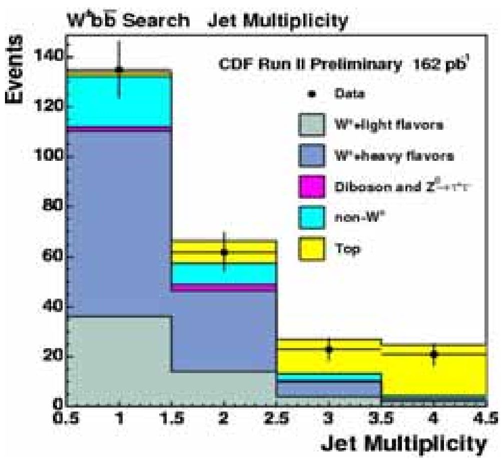
低・中間質量ヒッグス
$W^{\pm}$, Z^0 との随伴生成
$p\bar{p} \to HVX$, $H \to b\bar{b}$ or WW^*

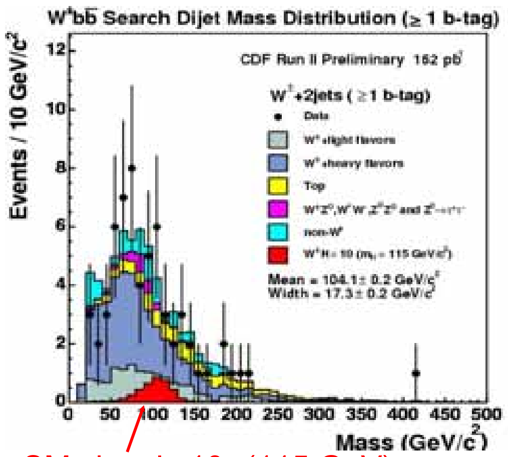
高質量ヒッグス
単一生成
$p\bar{p} \to HX$, $H \to W^+W^-$

$W^{\pm}$ との随伴生成 ： $p\bar{p} \to WHX \to (\ell\nu)\,(b\bar{b})$

終状態: W + two *b* jets
Analysis similar to top search, tag *b* jets.
But BG higher than in top search.

石澤善雄 博士論文予定
（筑波大学）

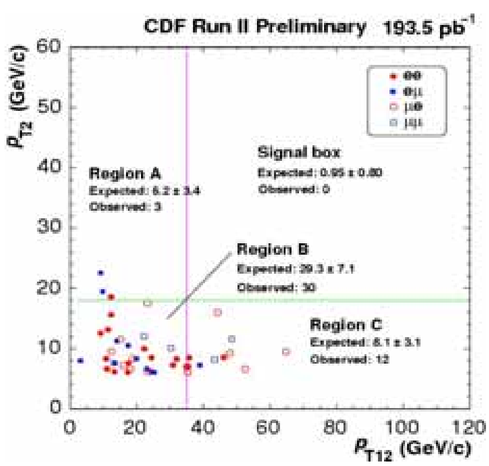


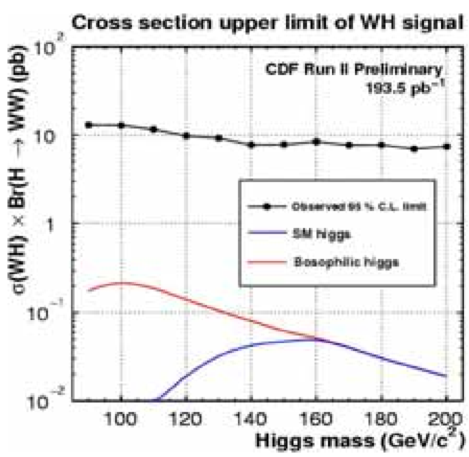


SM signal x10 (115 GeV)

$p\bar{p} \to WHX \to WWW^{(*)}X \to \ell^{\pm}\ell'^{\pm}Y$

終状態: **同電荷のレプトン対**

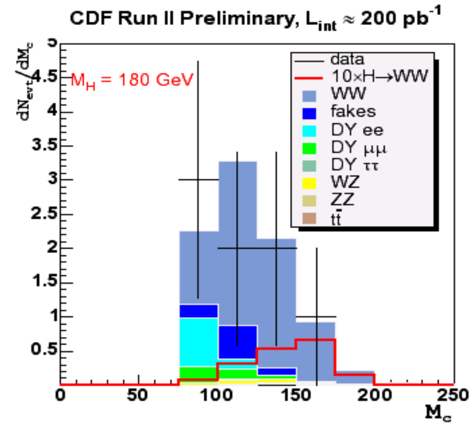




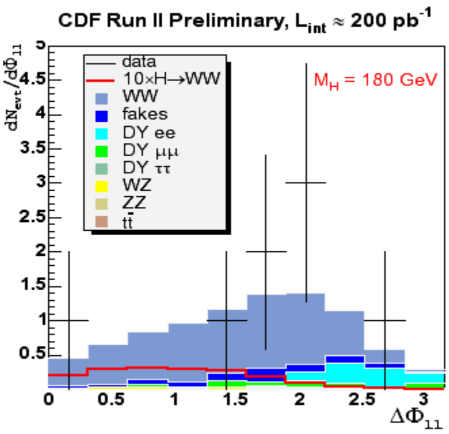
小林博和 博士論文 （筑波大学）
今大会講演 25aZB-2

$$p\bar{p} \to HX \to WW^{(*)}X \to \ell^{+}\ell'^{-}X$$

終状態：レプトン対, large missing energy, no jets
Main BG : electroweak W pair production

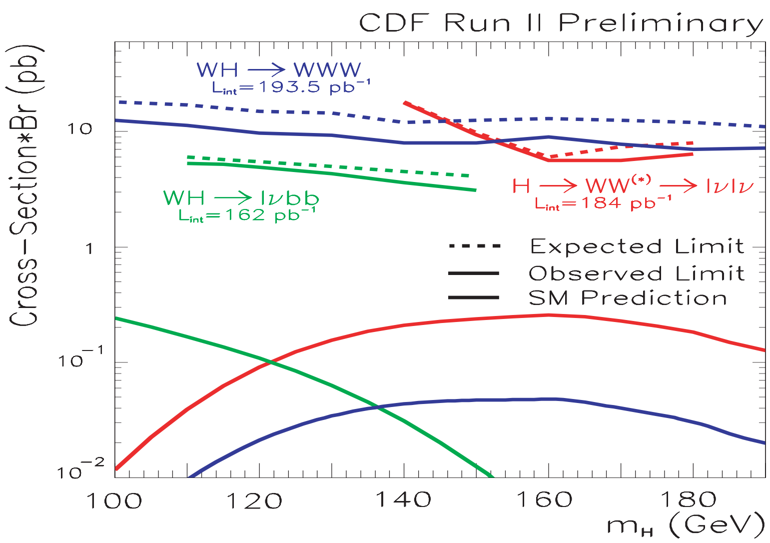


Leptons + missing E_T system mass



Opening angle of leptons

Higgs **粒子生成の探索のまとめ**

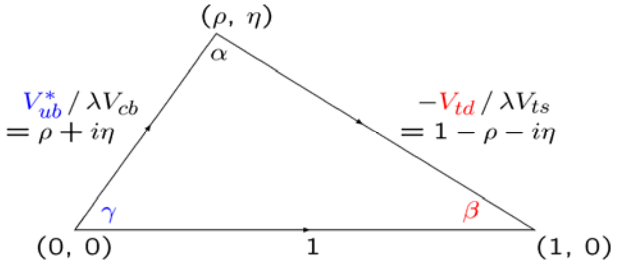


実験の上限値

標準理論の予言値

上限： 理論値の数十倍

B physics : does the unitarity triangle close?

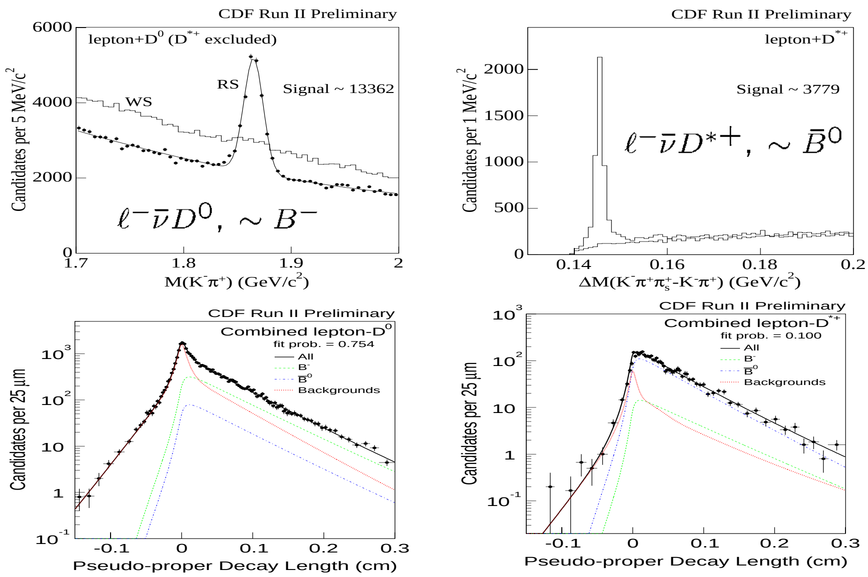


- $|V_{cb}|$ from $b \to c\ell\nu$, $|V_{ub}|$ from $b \to u\ell\nu$.
- $|V_{td}|$ from Δm_d, better if we use ratio

$$\frac{\Delta m_s}{\Delta m_d} = \left|\frac{V_{ts}}{V_{td}}\right|^2 \frac{m_{B_s}}{m_{B_d}} \xi^2 \quad (\xi = 1.14 \pm 0.03^{+0.13}_{-0.02})$$

- $\sin 2\beta$ from $B^0/\bar{B}^0 \to J/\psi K^0_S$. Now precisely known.
- α from $B^0/\bar{B}^0 \to \pi^+\pi^-$, etc.
- γ from $B \to DK$, etc.

B^-, $\bar{B}^0$ lifetimes using semileptonic decays



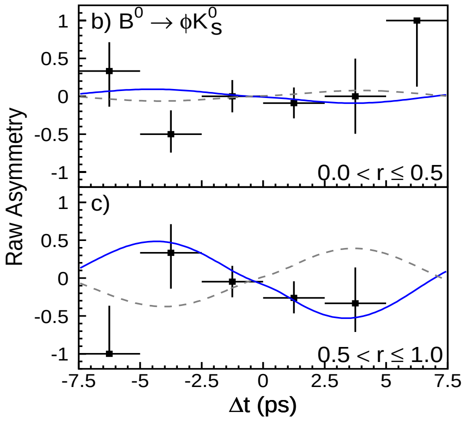
$\tau^- = 1.653 \pm 0.029 ^{+0.033}_{-0.031}$ ps, $\tau^0 = 1.473 \pm 0.036 \pm 0.054$ ps,

$\tau^-/\tau^0 = 1.123 \pm 0.040 ^{+0.041}_{-0.039}$ 魚住聖 博士論文 （筑波大学）

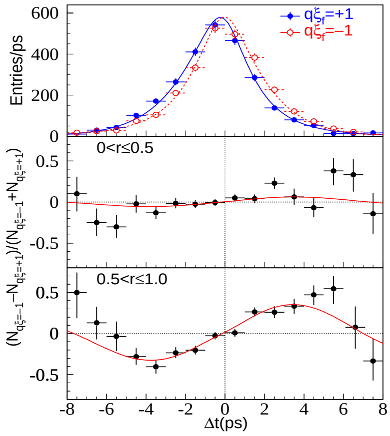
New physics in $b \to s$ transition ?

Belle : PRL 91, 261602 (2003)

$B^0/\bar{B}^0 \to \phi K_S^0\ (b \to s\bar{s}s)$



$B^0/\bar{B}^0 \to J/\psi K_S^0\ (b \to c\bar{c}s)$



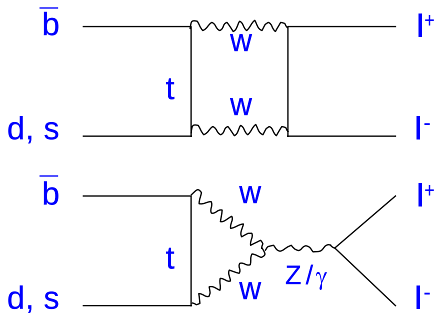
$\sin 2\beta = -0.99 \pm 0.50$, vs. $+0.731 \pm 0.056$.
3.5 σ away!

CDF 実験での $b \to s$ 遷移の検証 (SUSY?)
***B*-factory 実験と相補的な測定・観測量**

- Δm_s ： $B_s^0 \bar{B}_s^0$ 振動の振動数
  If $\gg 18\ \mathrm{ps}^{-1}$, a new particle in the loop.
- $B_s^0 \to J/\psi\,\phi$ 崩壊における $\Delta\Gamma_s \neq 0$ および CP の破れの探索.
  後者：標準模型では V_{ts} の位相のはず，つまり ~ 0 を予期.
- $B_d^0 \to \pi^+\pi^-$ および $B_s^0 \to K^+K^-$ 崩壊での CP 非対称度の測定
- 稀崩壊の探索： 例 $B_s^0 \to \mu^+\mu^-$.
  Extremely suppressed in SM, $\mathcal{B} \sim 10^{-9}$ predicted.

Rare decays $B_d^0/B_s^0 \to \mu^+\mu^-$

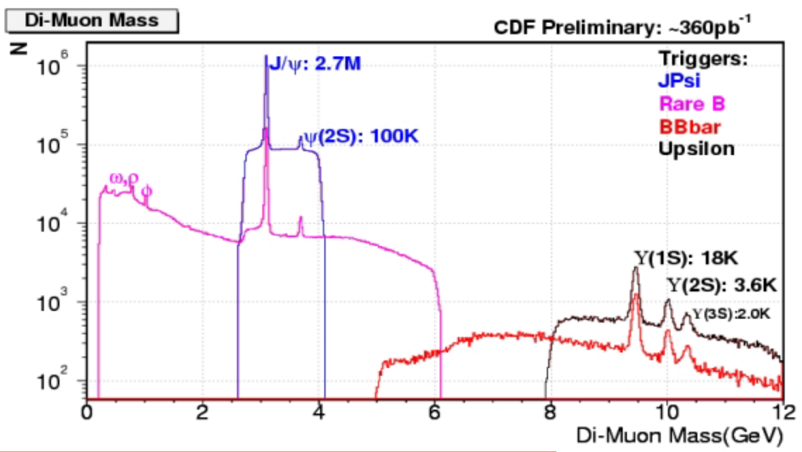
- V_{td} for B^0_d, V_{ts} for B^0_s
- FCNC
- Helicity suppressed.
- B.F. very small.



SM predictions for B.F.

- $B_d^0 \to \mu^+\mu^-$ $(1.00 \pm 0.14) \times 10^{-10}$
- $B_s^0 \to \mu^+\mu^-$ $(3.4 \pm 0.5) \times 10^{-9}$
- Five orders smaller for e^+e^- modes.

Run-II Di-muon data : CDF

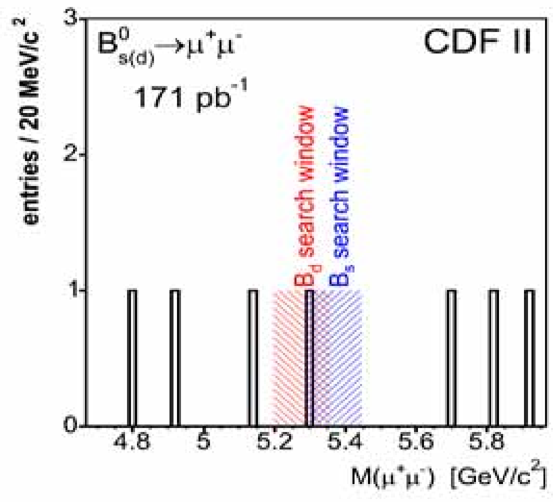


種々の共鳴状態を高統計で再構成

$\sigma(\bar{p}p \to J/\psi X)$ および $\sigma(\bar{p}p \to bX)$ の測定

山下智弘 博士論文 （岡山大学）

$B^0_d/B^0_s \to \mu^+\mu^-$ Search Result



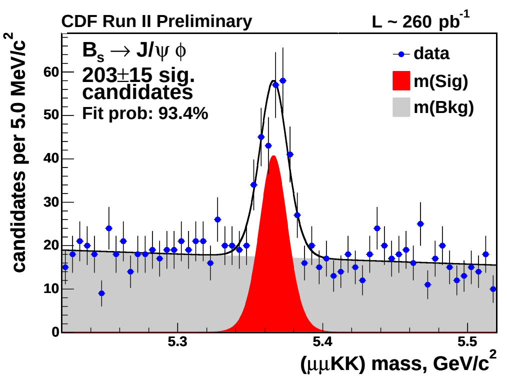
One candidate in the overlap region of B^0_d and B^0_s mass windows.

B.R. < 1.9 x 10^{-7} for B^0_d
B.R. < 7.5 x 10^{-7} for B^0_s
@ 95% C.L.
PRL 93, 032001 (2004)

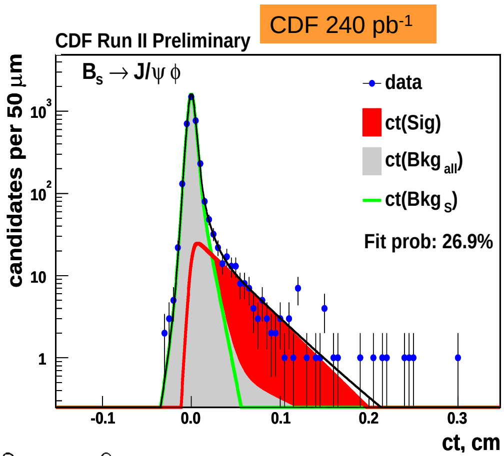
Previous CDF limits :
B.R. < 8.6 x 10^{-7} for B^0_d
B.R. < 2.6 x 10^{-6} for B^0_s
PRD 57, 3811 (1998)

近々 update **の予定** (360 pb^{-1}), 3**倍程度の改善を予期**

$B^0_s \to J/\psi\,\phi \to \mu^+\mu^- K^+ K^-$



CDF 240 pb^{-1}



$m(B^0_s) = 5366.01 \pm 0.73 \pm 0.33$ MeV$/c^2$

$\tau(B^0_s) = 1.369 \pm 0.100 \pm 0.010$ ps

Predict $\tau(B^0_s)/\tau(B^0_d) = 1.0 \pm \mathcal{O}(1\%)$
But expect $\Delta\Gamma_s/\Gamma_s \sim 0.1$.
Mode dominated by CP even
($\Gamma_\perp/\Gamma = 0.232 \pm 0.100 \pm 0.013$, CDF).

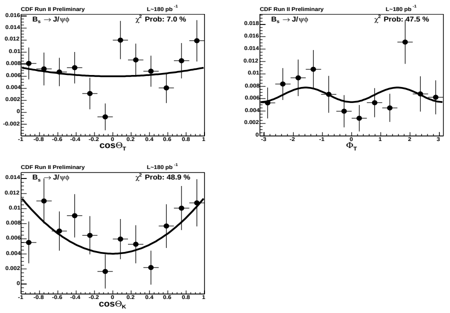
Can exhibit a different τ than in flavor eigenstates.
$\Delta\Gamma_s \neq 0$ may allow CP studies with untagged events.

Future : look for CP-violation, ~0 expected in SM, arg(V_{ts}).

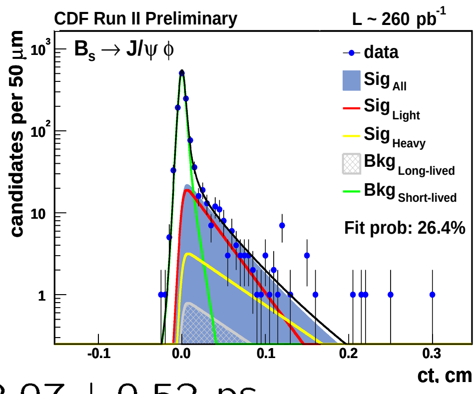
$B_s^0\bar{B}_s^0$ 系における寿命差 $\Delta\Gamma_s$ の探索

終状態 $B_s^0 \to J/\psi\,\phi \to \mu^+\mu^-K^+K^-$ はCP固有状態の重ね合わせ → 寿命２成分

確率分布 $P(t) = \frac{f_L}{\tau_L}\,e^{-t/\tau_L} + \frac{1-f_L}{\tau_S}\,e^{-t/\tau_S}$



$f_L = \Gamma_\perp/\Gamma = 0.232 \pm 0.100 \pm 0.013$

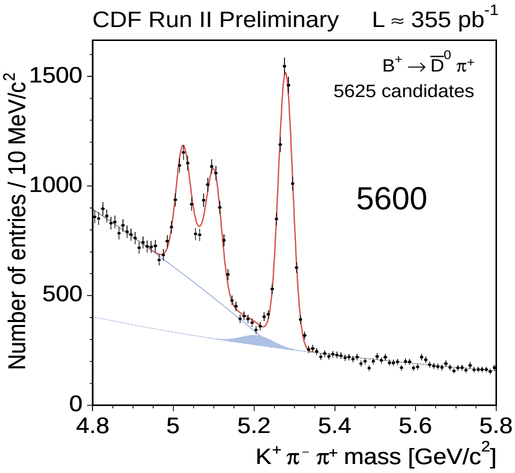


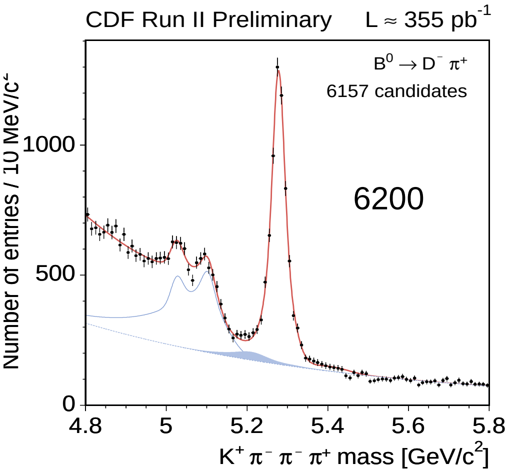
$\tau_S = 1.05 \pm 0.15$ ps, $\tau_L = 2.07 \pm 0.52$ ps.

$\Leftrightarrow \quad \bar{\tau} = 1/\Gamma = 1.40 \pm 0.14$ ps, $\quad (\Delta\Gamma/\Gamma)_s = 0.65\,^{+0.25}_{-0.33}$

B signals from CDF SVT triggers : full reconstruction

$B^- \to D^0\pi^- \to (K^-\pi^+)\,\pi^-$ $\quad\quad$ $\bar{B}^0 \to D^+\pi^- \to (K^-\pi^+\pi^+)\,\pi^-$





Calibration modes for $B_s^0\bar{B}_s^0$ oscillations.
Understand proper time resolution and flavor tagging

$B_q^0 \bar{B}_q^0$ Oscillations $(q \equiv d, s)$

$$\mathcal{P}_{\text{unmix}}(t) = \frac{1}{2\tau} e^{-t/\tau} (1 + \mathcal{D} \cos \Delta m\, t)$$

$$\mathcal{P}_{\text{mix}}(t) = \frac{1}{2\tau} e^{-t/\tau} (1 - \mathcal{D} \cos \Delta m\, t)$$

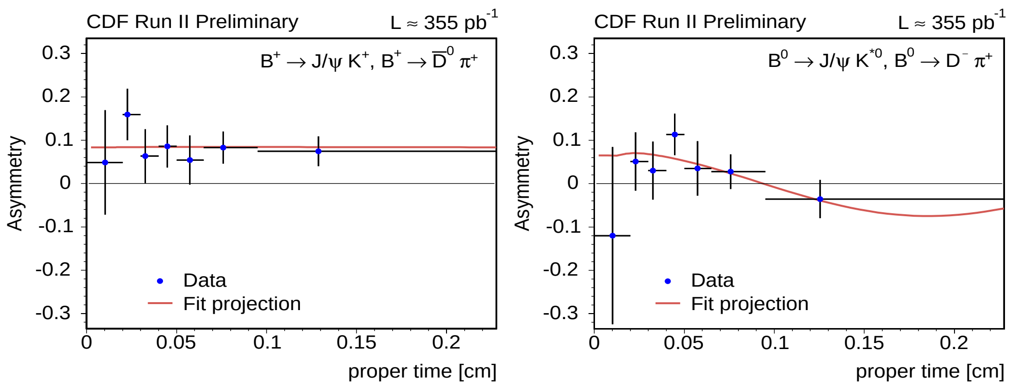
$\mathcal{D}$ is an experimental factor, called "dilution", reflecting an incompleteness in initial flavor determination.

測定の手順

- Reconstruct B meson decay with flavor-specific final state, such as $D\pi$ and $\ell\nu D$.
- Measure decay length L and momentum p
- Extract proper decay time $ct = \frac{L}{\beta\gamma} = L\frac{m}{p}$
- Determine the initial flavor, B^0 or $\bar{B}^0$
- Fit for Δm, and optionally for $\mathcal{D}$ (in B_d^0 and B^+)

Measure flavor tagging using B^+ and B^0 decays

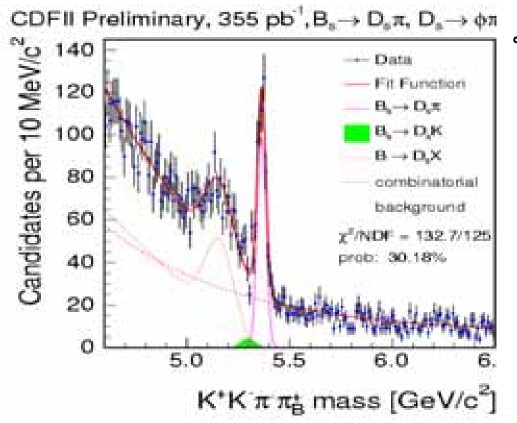
$$\mathcal{A}_{\text{mix}}(t) = \frac{N(t)_{\text{unmix}} - N(t)_{\text{mixed}}}{N(t)_{\text{unmix}} + N(t)_{\text{mixed}}} = \mathcal{D} \cos(\Delta m\, t)$$



$\varepsilon D^2 = (1.1 \pm 0.2)\%$

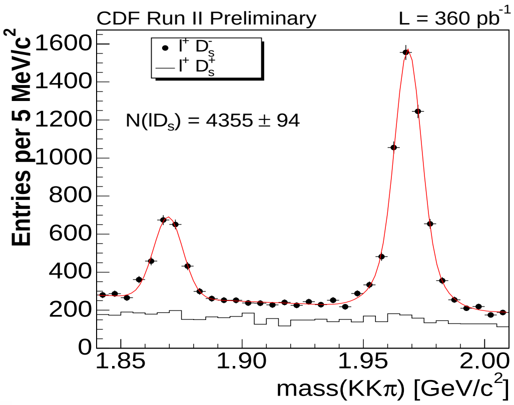
Toward $B_s^0 \bar{B}_s^0$ oscillations

$\bar{B}_s^0 \to D_s^+ \pi^- \to (\phi\pi^+)\,\pi^-$



Total hadronic : 900±43

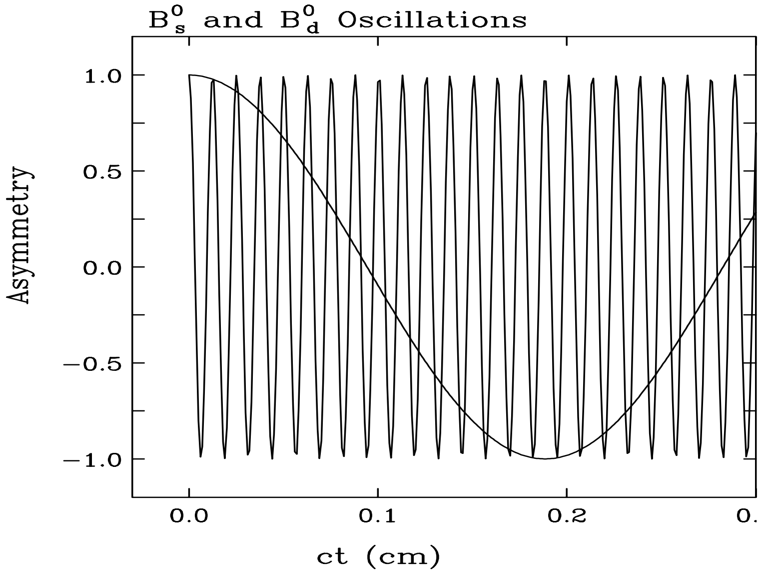
$\bar{B}_s^0 \to \ell^- \bar{\nu} D_s^+ X$



Total semileptonic 7700±150

Measurement along the way: $c\tau$ (B^0_s) = 479 ± 29 (stat.) ± 5 (syst.) μm
(PDG = 438 ± 17 μm)

Oscillations with $\Delta m = 0.5$ ps^{-1} and 15 ps^{-1}

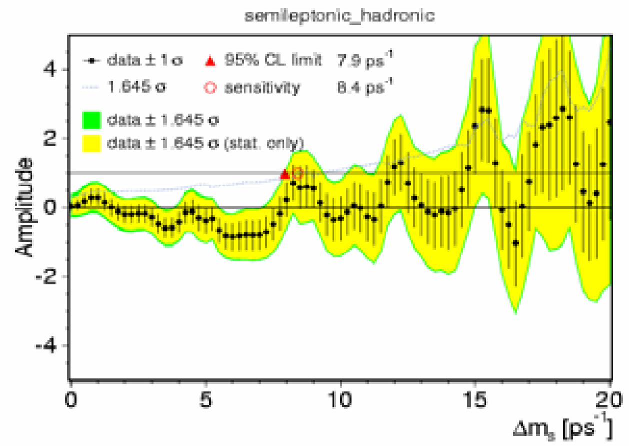


$\sigma_t < 100$ fs is necessary and achieved.

Search for $B_s^0 \bar{B}_s^0$ oscillations : amplitude scan

$1 \pm \mathcal{D} \cos \Delta m\, t \;\rightarrow 1 \pm A\mathcal{D} \cos \Delta m\, t$, then fit for A

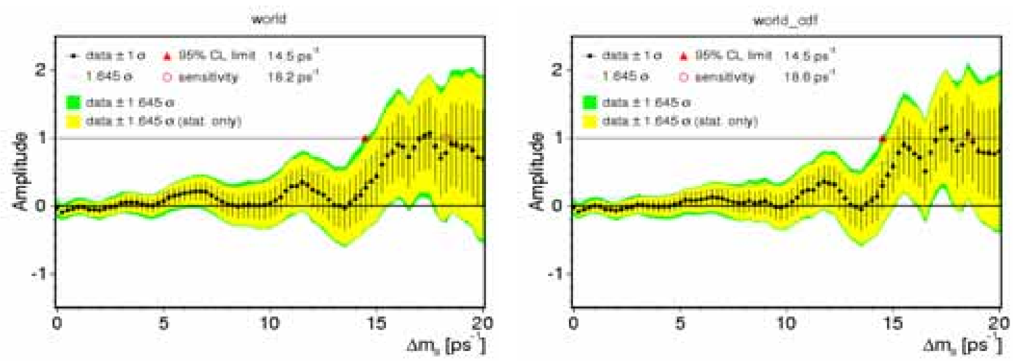
フーリエ解析：振動が起こっていれば振幅Aが1となる



Limit :
$\Delta m_s > 7.9$ ps^{-1}
95% C.L.

Best single experiment limit is 10.9 ps^{-1} (sensitivity 15.2 ps^{-1})

Impact on World Average Sensitivity



We increase sensitivity by 0.4 ps^{-1}, limit is unchanged

Improvements for summer 2005
- more signals (more decay modes, better trigger)
- same-side (kaon) tagging → could be a factor of 2-4
- improve ct resolution

Summary

Tevatron Run-II in progress since 2001 :

- Machine luminosity vastly improved, delivered > 850 pb^{-1} to each experiment.
- CDF recorded ~650 pb^{-1}.
  - 6×Run-I total. More to come.
- Top production reconfirmed, new precision / measurements coming.
- Electroweak physics :
  - Precision $M_W \rightarrow$ indirect Higgs mass. Triple-Gauge couplings.
- Enhanced *B* physics capabilities :
  - Many ways to test CKM triangle, $b \rightarrow s$ transition in particular.
- Expect to collect ~2 fb^{-1} in the near future (early 2006?), and to make some significant measurements before LHC. Surprises welcome, too!